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AEROSTAT COLD WEATHER STUDY

D. L. Kane

13 March 1989

Technical Report
Contract No. MDA 972-88-C-0020

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The arctic environment and its potential impact on Aerostat design and operations are discussed. Predictive meteorological resources available are summarized. Results of previous Aerostat operations in cold climates are reviewed and potential solutions discussed for the problems encountered.

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PREFACE

This report summarizes a review of available technical literature related to the operational availability and lessons learned from aerostat systems operated in high latitudes, on islands, ice flows, and in remote areas. In addition, a feasibility analysis related to operation in the above areas has been completed for the mechanical subsystems of an aerostat system, including the aerostat itself, the tether, mooring subsystems, and the electrical feed. No specific site has been identified; the information provided is for cold arctic regions in general.

Information on aerostat operations under the above conditions is scarce due to the paucity of actual operations and the restrictions on the release of data from such operations.

Following is an outline of topics to be discussed herein: (1) the Arctic environment and its potential impact on aerostat operations, (2) review of predictive resources available to a system operated in the Arctic, (3) results of previous aerostat and airship operations and tests, (4) potential impact on Aerostat Supported ELF/VLF Transmitter (ASET) system operation and potential methods to alleviate this impact.

The subject matter of this report is very broad, and no attempt will be made to cover all areas in depth. References will be restricted to those that are most pertinent, and contain specific data on prior testing, calculations, and solutions. This report is an overview of a system design that would apply the details of other reports toward specific solutions for an ASET system.

LIST OF FIGURES

LIST OF TABLES

I. BACKGROUND

Aerostat systems have become a permanent part of U.S. government systems, and are utilized by the U.S. Air Force (USAF), U.S. Coast Guard (USCG), and U.S. Customs Service (USCS). The USAF operates medium-size aerostats of approximately 256,000 ft^3 (Fig. 1) to provide midaltitude (10,000-12,000 ft) radar coverage of the southeastern border from Florida. The USCS has been operating somewhat larger aerostats in the Grand Bahama Islands (Fig. 2) for some years, and will soon be operating systems up to 595,000 ft^3 in Fort Huachuca, Arizona; Deming, New Mexico; and other southern border locations, again as midlevel radar stations. For drug interdiction purposes, the USCG operates small aerostats from ships operating up and down the entire length of the Atlantic seaboard. Current plans call for five or more systems to be added to the one already in operation. Future USCG operations may also include the western seacoast of the U.S. Finally, experimental systems have been operated by the Defense Advanced Research Projects Agency (DARPA) and the Air Force Geophysical Laboratory (AFGL) to research new missions and explore the operational envelope of aerostat systems.

The USAF and USCS locations are land-based and present operational challenges specific to their locations. The sites in Florida (Fig. 3) and the Grand Bahama Islands offer no protection from the elements, and are subject to serious weather hazards due to thunderstorms and hurricanes, with lightning and high winds as severe as any place on Earth.

The USCG is currently the only operator of sea-based aerostat systems in the U.S. These systems utilize small aerostats (approximately 56,000 ft^3) which operate off converted utility vessels (Fig. 4), and function as low altitude (approximately 2000-3000 ft) radar stations. The Coast Guard systems have the widest range of operational exposure, extending from as far north as Newfoundland to as far south as the Caribbean Sea, on an operational schedule which is much more demanding than any other site.

Aerostat systems in the Florida Keys operate in steady state

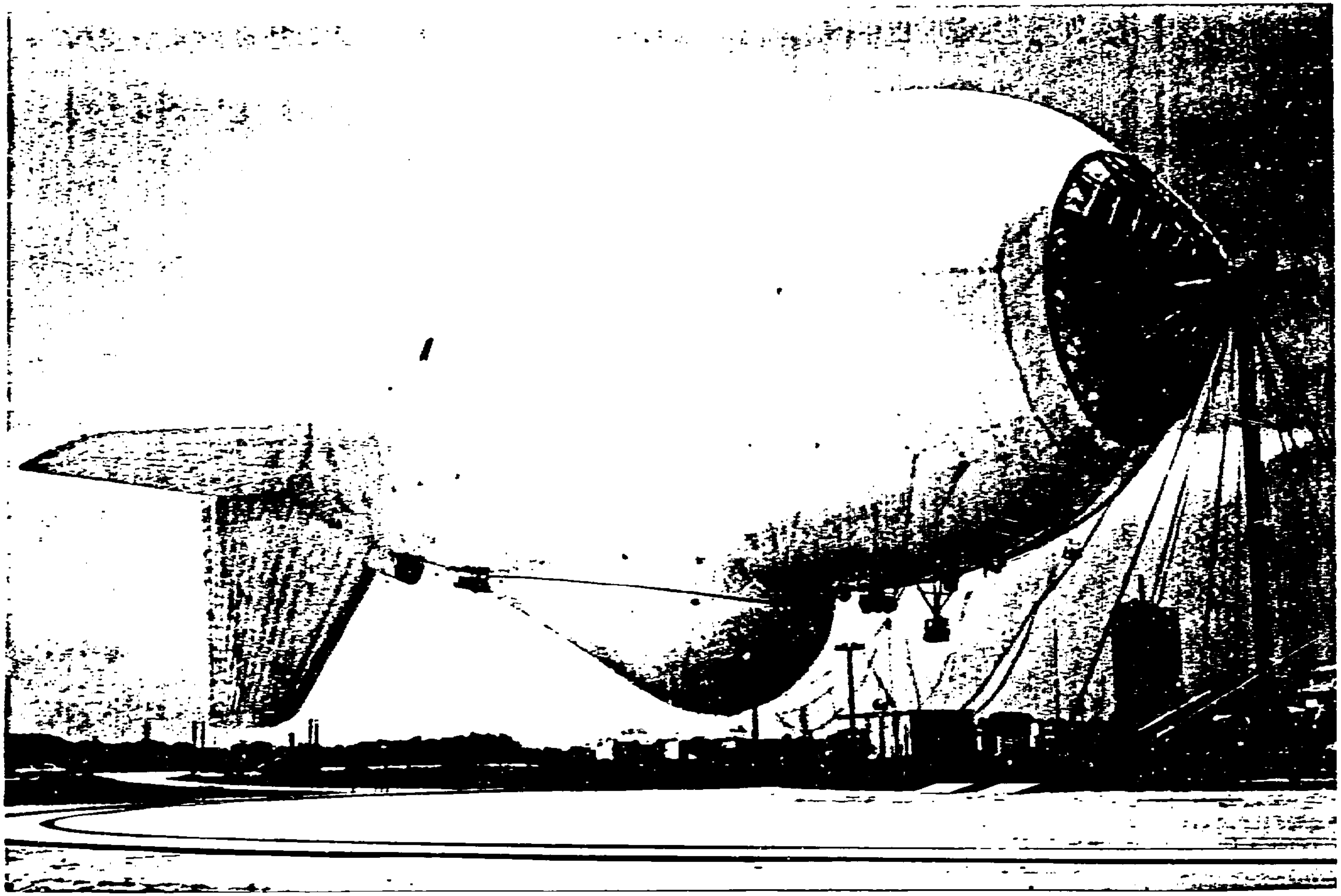


Figure 1. USAF Seek Skyhook aerostat system - Cape Canaveral AFS, Florida.

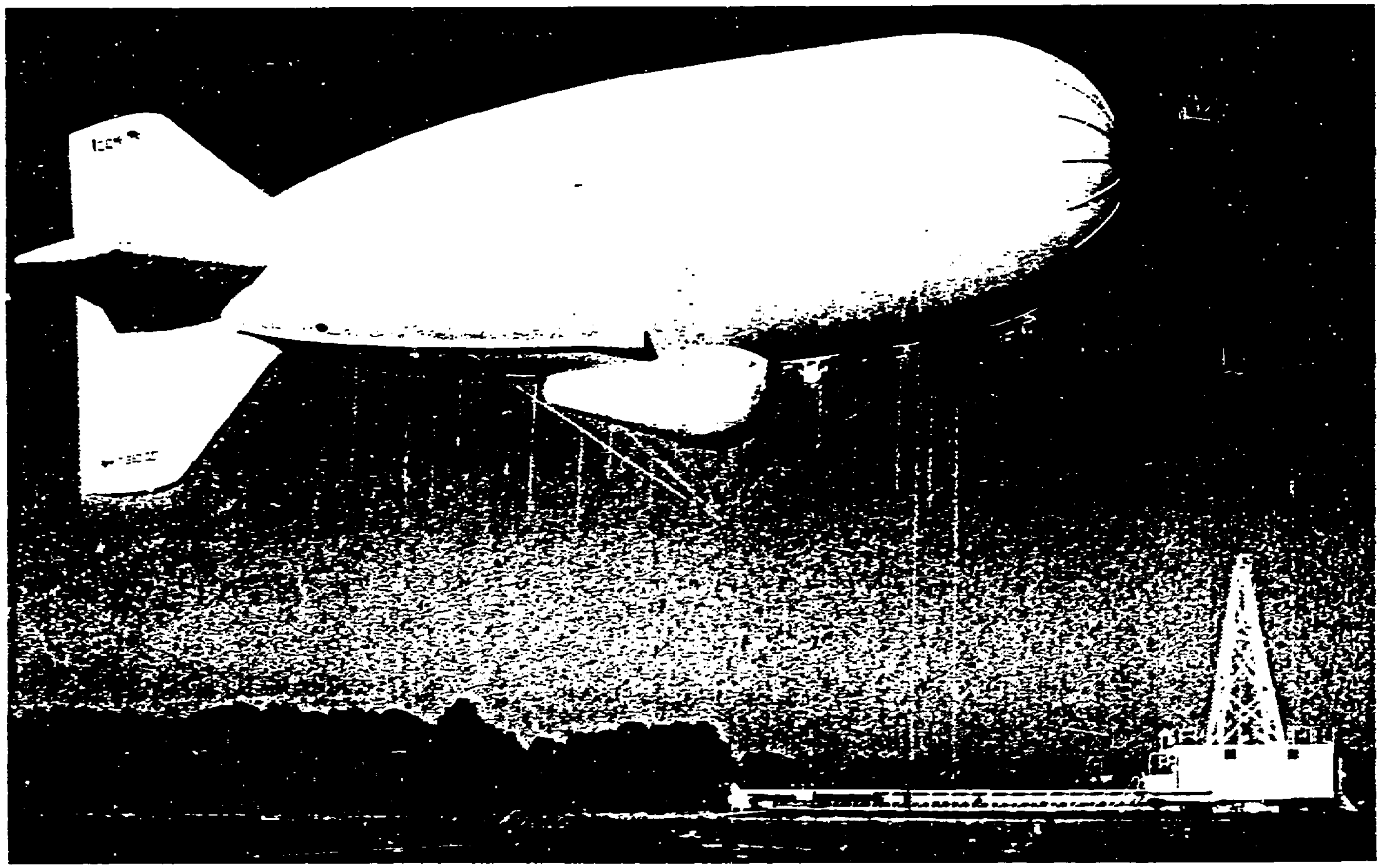


Figure 2. USCS Grand Bahama Islands aerostat system.

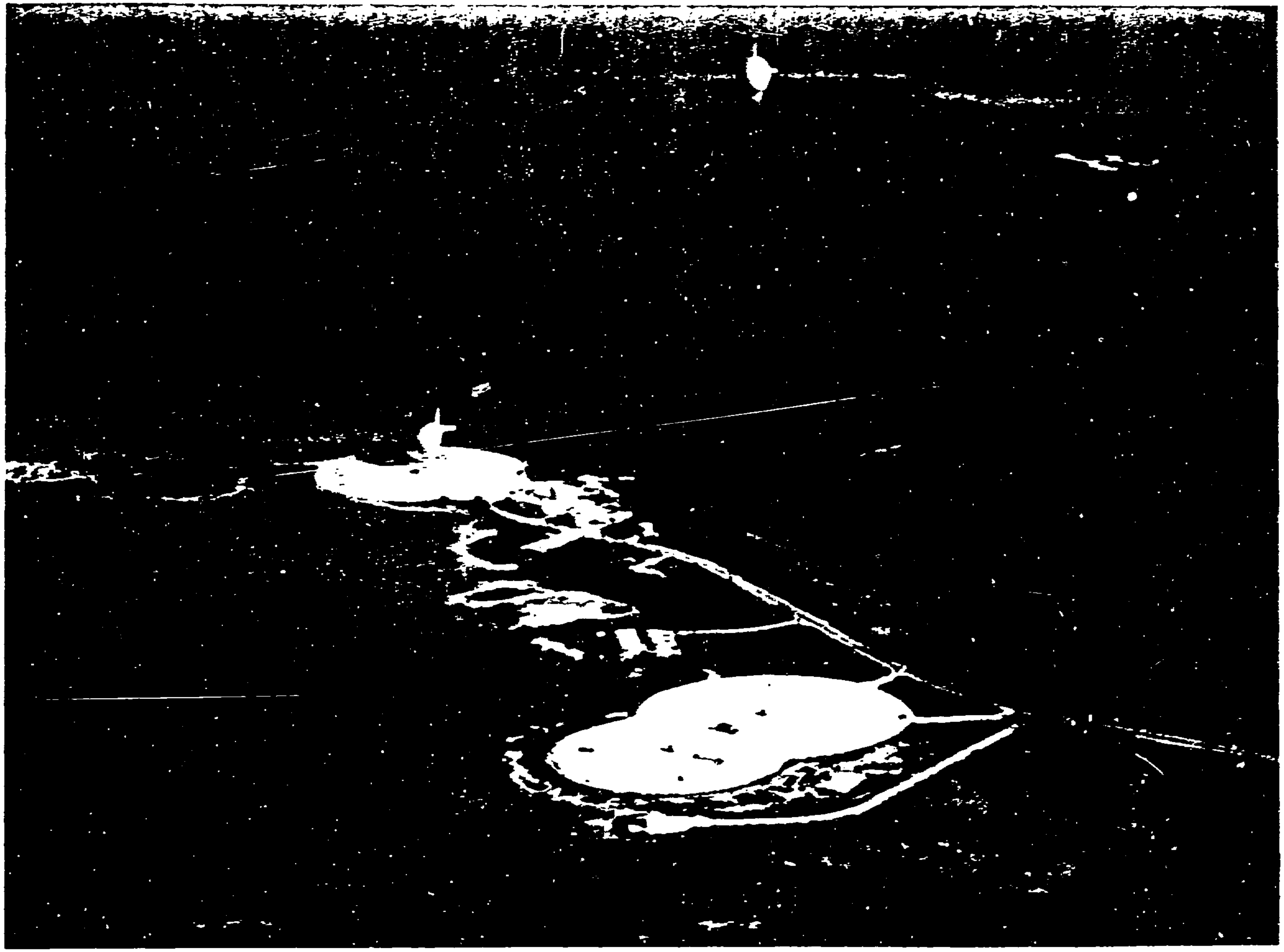


Figure 3. USAF Seek Skyhook aerostat system - Cudjoe Key AFS, Florida.

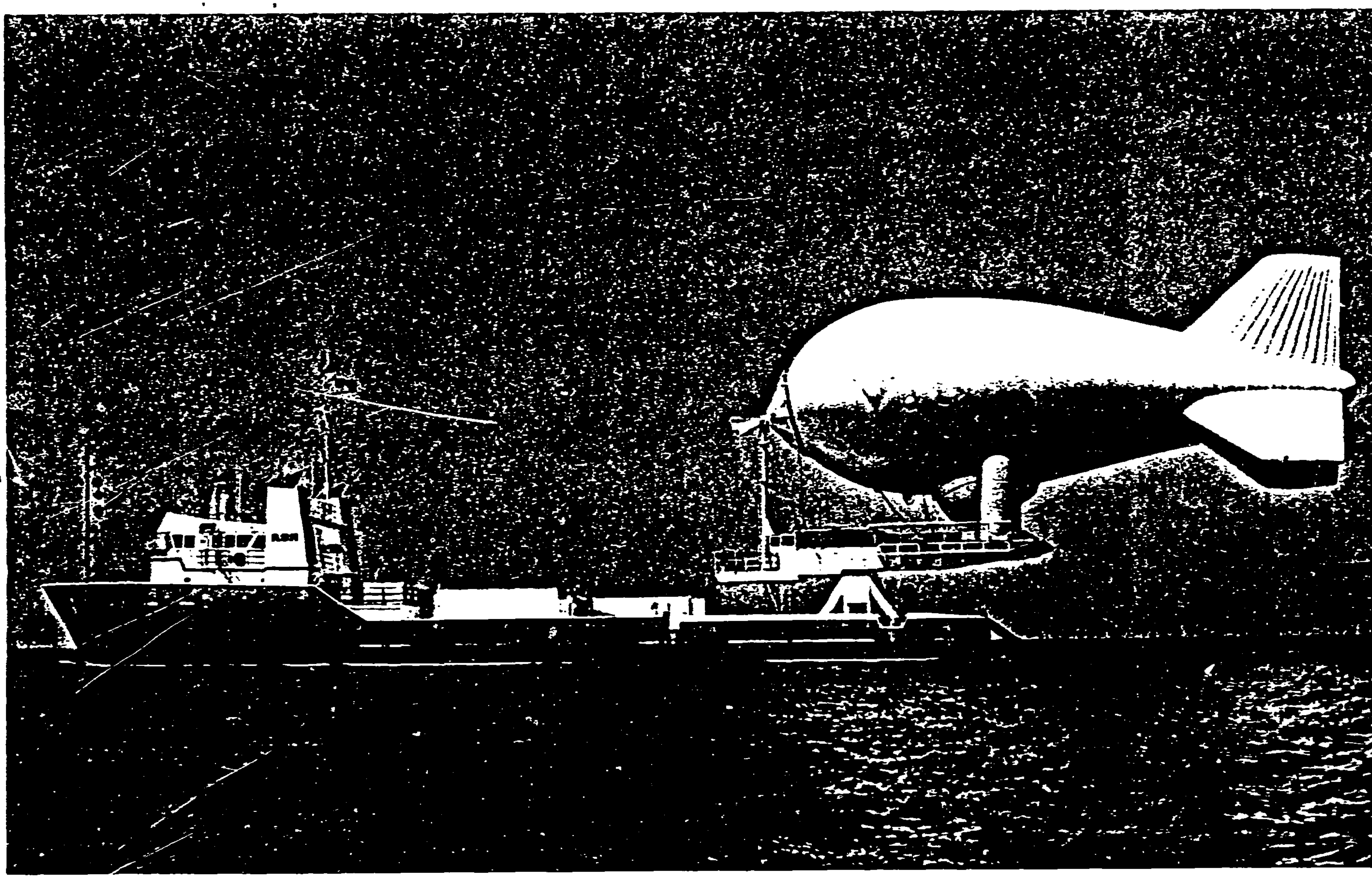


Figure 4. USCG shipboard aerostat system at sea.

winds above 50 kn on a routine basis [1]. Wind speeds in excess of 60 kn have been recorded with the aerostat both flying and moored, but this is not a frequent occurrence. Wind speeds of 35 kn and above place restrictions on launch and recovery operations as they are currently conducted [1]; however, the systems presently in use by the Air Force do not reflect either high mission priority or design optimization for rugged weather operation. Wind speeds up to 90 kn have been reported with the aerostat moored to its tower during hurricane passage [2]. While these winds are not as high as the peak winds at some specific locations in the North, they are fully representative of the severity of the wind hazard likely to be faced by a well-planned aerostat operating site in the North.

None of the production systems have been tested in icing conditions as severe as might be found in the Arctic. Ice does occur at some of the current land sites, but the operational impact of ice and snow at these locations is essentially negligible and can be ignored.

The USCG has operated a system in icing conditions off the northeastern U.S., but only for very limited periods, as the system was not designed for this purpose [3]. The AFGL has operated a small (25,000 ft^3) system at the Ethan Allen Firing Range for a limited time, and the results of those tests have been reported [4]. Also, various commercial companies operated aerostat systems in northern climates for commercial and military missions in the late 1970s and early 1980s [5]. These operations, however, were not documented, so results are not generally available.

II. THE ARCTIC ENVIRONMENT

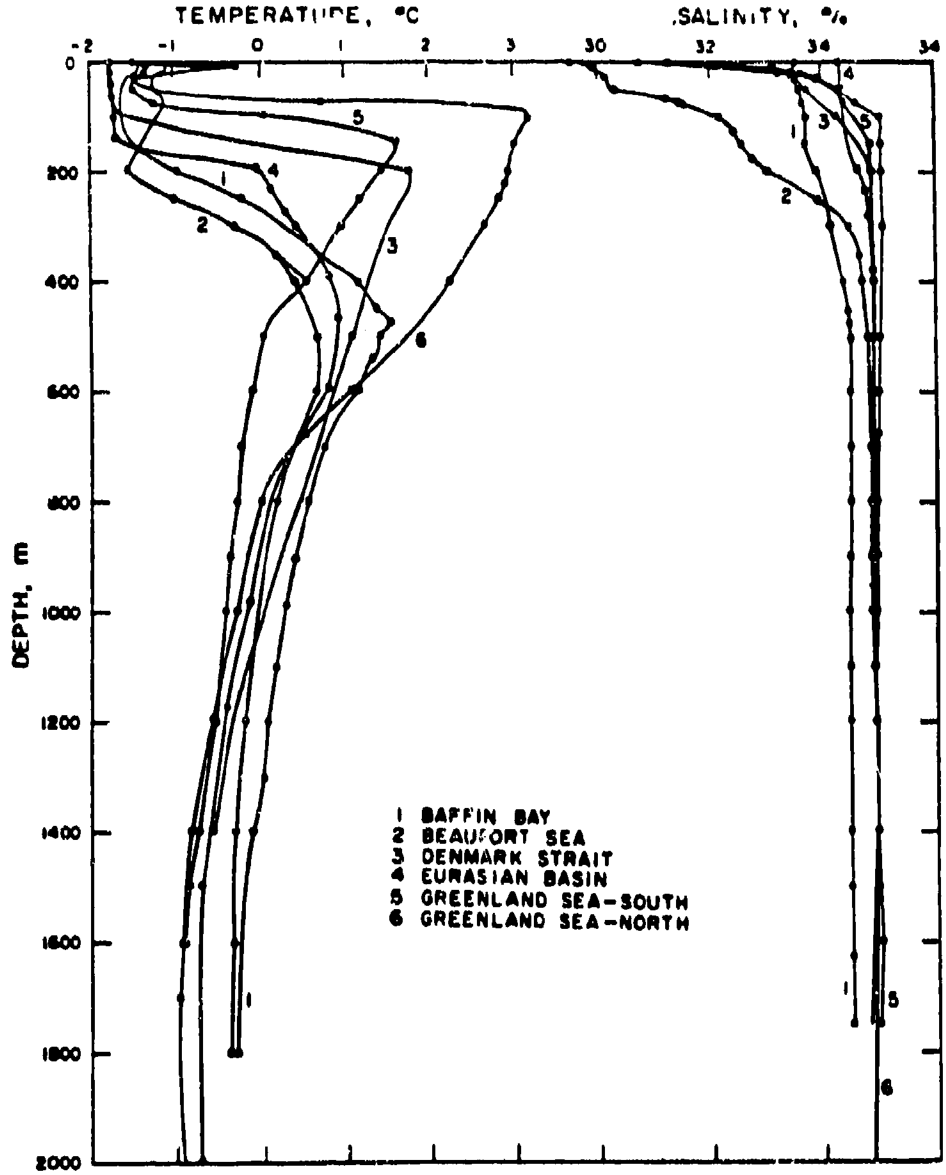
The environmental factors of interest to operating an aerostat in the Arctic are temperature, wind velocity and variability, restrictions to visibility, snow and ice accumulation, and windchill. For this report these weather phenomena will be reviewed for the area between 50° and 65° North. Since an aerostat system can be either land- or sea-based, weather in both of these regimes will be explored.

While it is true that the northern latitudes can present some very extreme weather [6], these extremes are not necessarily the values which should be used as specifications in a systems design. Rather, the meteorological weaknesses and strengths of an aerostat system should be understood and candidate sites selected which will be most compatible with these characteristics. Aerostat systems can be built durable enough so that site requirements are not a major limitation on their operational employment in northern latitudes.

WATER AND AIR TEMPERATURE

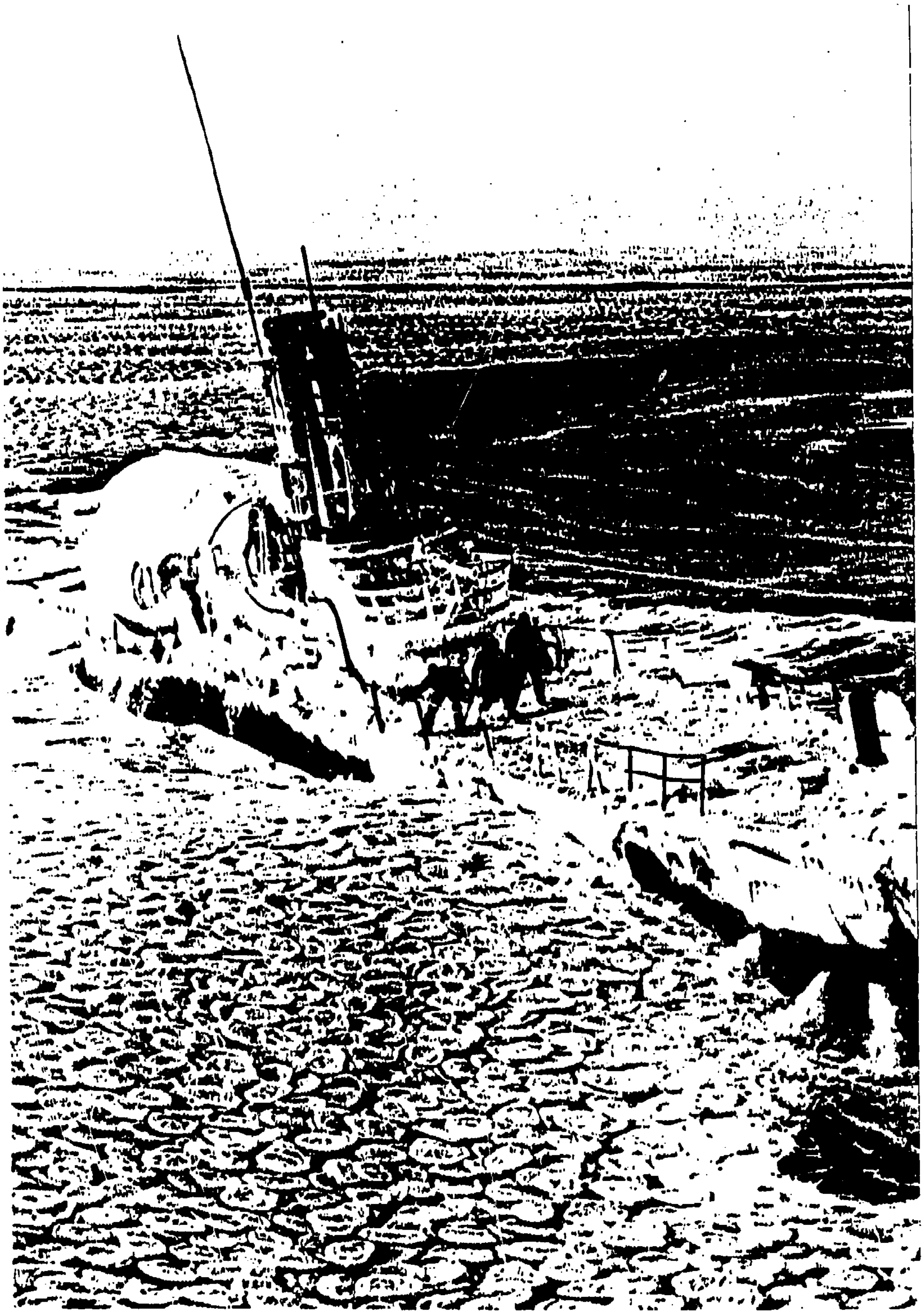
Sea water temperatures at the surface in the Arctic areas of North America, Greenland, and Iceland are uniformly near or slightly below freezing. Figure 5 indicates sea water temperature in six regions of interest ranging from surface level to depths beyond the scope of this report. The significance of this uniformity is in its impact on coastal air temperatures and on the formation of freezing spray aboard vessels at sea.

Sea water of this temperature will present a significant icing problem for smaller vessels as the sea state increases. Since the surface water is generally at or below freezing, superstructure icing occurs very rapidly in sea state five or greater, when the air temperature is below freezing [8]. Wind driven, supercooled spray is deposited on the superstructure and lines, forming a very fast ice layer whose size increases exponentially with time [9]. If design provisions are not made to prevent ice formation, Fig. 6 may be indicative of deck and structure ice formation to be expected on a



Source: [7].

Figure 5. Sea temperature versus depth profile.



Source: [8].

Figure 6. Surface and superstructure icing in platelet sea ice.

vessel with little freeboard in an arctic environment.

Monthly air temperature data [7] for several locations in the North is indicated in Fig. 7. Absolute maximum and minimum, mean maximum and minimum, and mean air temperatures are plotted over the entire year. Temperature variation can range from as high as 120°F to as low as 40°F depending on frontal passage, proximity to mountain passes, coastal proximity, and other variables.

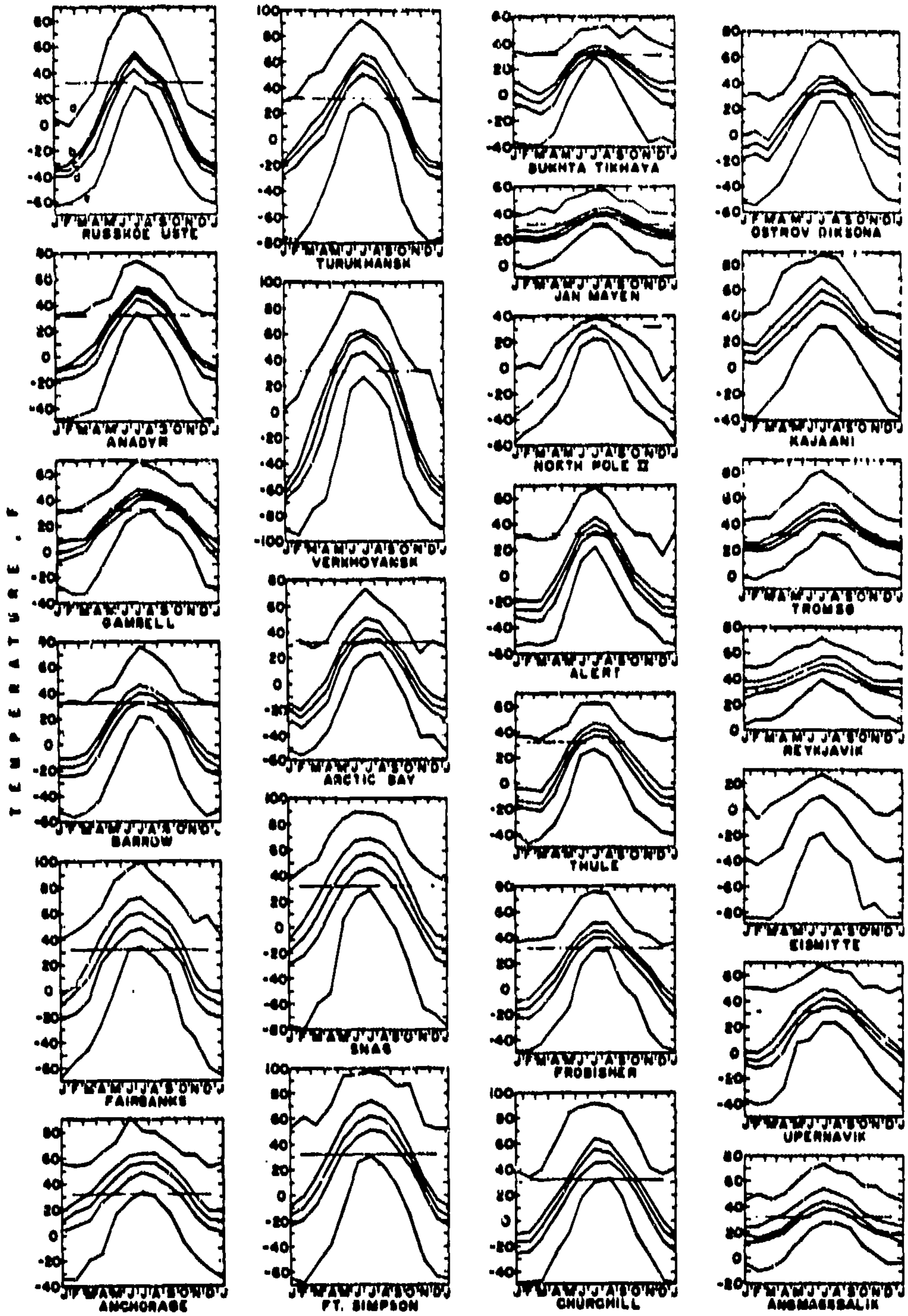
Long-term, monthly, mean upper air temperature data is available (Fig. 8) and indicates that the temperature in the atmosphere more closely approximates the world norm than the surface temperatures do [10].

WIND SPEED AND DIRECTION

Mean wind speed and direction data for several points in the arctic areas of North America, Greenland, and Eurasia are indicated in Fig. 9. Both the mean and fastest wind speed data is indicated for several locations in Alaska, and data for winds of gale force (32 kn) or greater is indicated for some Eurasian locations. The mean wind speed in many locations is quite low (below 10 mph). Islands and exposed coastal locations near cyclone tracks, as well as areas subjected to exit winds of mountain passes have higher mean wind speeds (averaging below 20 mph) [7]. The U.S. Air Force Environmental Technical Applications Centers (USAFETAC) has compiled statistical data for many military sites in the North.

Mean and maximum wind information is very important to aerostat operation in order to prevent damage to the hull while it is being laid out for attachment of hull hardware, and during actual inflation. Therefore the lowest possible winds are desirable until the hull takes shape and the drag coefficient is controllable.

For inflation, wind speeds of 10 mph or less are desired for a period of 8 h or more. Higher wind speeds would be tolerable if a fence or some other sheltering structure were provided for inflation. A low value for mean winds indicates there is a high probability that such an 8 h period of low winds would be available. Mean surface winds of the values indicated in Fig. 9 indicates that there is a high



a) Absolute maximum; b) Mean maximum; c) Mean;
d) Mean minimum; e) Absolute minimum.

Source: [7].

Figure 7. Monthly temperature distribution at selected stations.

Columns: LEVEL (Pressure mb, Height gpm) — TEMPERATURE (Missing days, Mean °C, Dew point depression °C) — VECTOR WIND (Missing days, Steadiness %, Direction °, Speed mps)

AFRICA - SOUTH AFRICA, GOUGH ISLAND, 4021S 00953W OB 1

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030	23821	6	-55.4		6	98	285	32
050	20557	4	-57.2		4	97	285	28
100	16189	1	-57.6		1	97	279	30
150	13625	1	-55.8		1	95	277	35
200	11793	1	-55.2		1	93	274	35
300	9162	1	-45.0	12.3	1	90	280	30
500	5569	1	-20.1	13.0	1	91	282	23
700	2999	1	-4.5	12.6	1	92	283	16
850	1450	1	2.1	3.9	1	87	284	12
1008	*		9.8	2.4				

AFRICA - SOUTH AFRICA, MARION ISLAND, 4653S 03752E OB 1

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030								
050	20474	6	-53.6		6	97	278	48
100	16108	0	-55.0		1	96	276	40
150	13517	0	-54.6		0	95	273	38
200	11681	0	-56.3		0	91	271	40
300	9069	0	-46.4	21.2	0	86	273	34
500	5494	0	-21.8	23.2	0	84	277	24
700	2946	0	-6.9	22.8	0	88	276	19
850	1413	0	-0.4	14.1	0	85	278	15
1010	*		4.4	2.2				

N AMERICA - USA, BARROW/W POST W ROGERS, AK, 7118N 15647W OB 2

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030	23208	12	-54.9					
050	20308	7	-55.6		9	92	243	13
100	15875	5	-52.7		6	85	227	8
150	13242	4	-51.6		4	69	211	6
200	11382	2	-51.9		2	51	190	5
300	8775	1	-53.9		1	34	141	4
500	5330	1	-30.3	7.1	1	35	148	3
700	2853	1	-14.6	7.9	1	50	127	3
850	1364	1	-8.7	5.9	1	50	113	4
1010	* 4		-5.2	1.3				

N AMERICA - USA, BARTER ISLAND, AK, 7008N 14338W OB 2

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030								
050								
100	15899	2	-52.6		2	92	247	10
150	13271	2	-51.2		2	90	233	9
200	11401	2	-51.7		2	73	217	7
300	8793	1	-53.2		1	54	205	8
500	5339	0	-29.8	7.7	0	53	205	5
700	2858	0	-13.4	6.8	0	37	198	2
850	1358	0	-6.2	6.5	0	28	154	2
1008	* 15		-4.6	1.4				

N AMERICA - USA, KOTZEBUE, RALPH WIEN, AK., 6652N 16238W OB 1

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030	23573	7	-52.8		9	89	252	15
050	20420	6	-52.6		8	88	239	11
100	15909	3	-50.3		4	79	219	8
150	13255	3	-49.3		4	77	205	7
200	11368	3	-49.0		4	64	186	6
300	8730	3	-53.3		4	51	159	7
500	5294	2	-31.0	6.3	3	53	142	5
700	2825	2	-14.8	6.9	2	51	138	4
850	1331	2	-6.6	3.3	2	50	119	4
1005	* 5		0.6	3.5				

N AMERICA - USA, NOME, AK., 6430N 16526W OB 2

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030								
050								
100	15865	5	-50.7		7	77	226	7
150	13213	4	-49.9		5	74	212	6
200	11338	3	-49.6		4	46	209	4
300	8708	2	-53.4		3	15	161	2
500	5269	1	-31.3	7.1	2	19	125	2
700	2802	1	-14.7	5.4	2	36	120	3
850	1306	1	-6.1	3.2	3	53	108	3
1001	* 7		-0.1	2.9				

N AMERICA - USA, BETHEL/BETHEL AIRPORT, AK., 6047N 16148W OB 2

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030	23731	8	-52.4		8	85	252	9
050	20431	8	-52.1		8	88	237	9
100	15940	1	-50.2		1	83	233	9
150	13284	1	-48.8		1	83	231	9
200	11391	1	-47.9		1	71	232	9
300	8733	1	-51.0		1	48	231	8
500	5279	0	-31.0	6.9	1	41	201	4
700	2806	0	-13.8	5.8	1	52	195	4
850	1304	0	-4.4	3.2	0	54	195	4
996	* 46		-0.1	0.8				

N AMERICA - USA, ANCHORAGE/INT., AK., 6110N 15001W OB 2

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030	23737	8	-55.0		9	88	248	11
050	20469	6	-54.5		6	87	246	9
100	15989	0	-51.3		0	94	232	12
150	13347	0	-50.2		0	91	222	13
200	11466	0	-49.4		0	91	220	14
300	8825	0	-51.2		0	78	207	17
500	5352	0	-28.9	5.9	0	83	195	11
700	2860	0	-12.5	4.5	0	72	172	8
850	1348	0	-2.9	3.8	0	57	141	5
999	* 40		3.9	4.1				

N AMERICA - USA, COLD BAY, AK, 5512N 16243W OB 2

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030	23857	9	-51.7	—				
050	20498	7	-53.0		8	86	237	7
100	15797	1	-51.0		3	92	241	12
150	13355	1	-49.9		4	89	240	14
200	11470	1	-48.8		5	81	250	16
300	8812	1	-49.2		1	75	251	18
500	5330	1	-28.9	7.2	1	74	239	10
700	2839	1	-12.5	5.8	1	62	248	8
850	1330	1	-3.9	2.2	2	45	239	6
999	* 31		3.8	2.4				

N AMERICA - USA, YAKUTAT, AK., 5931N 13940W OB 2

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030	23381	12	-53.9					
050	20514	9	-55.5					
100	16065	0	-53.7		4	94	246	13
150	13454	0	-52.3		5	90	244	16
200	11507	0	-51.3		6	90	246	19
300	8950	0	-49.2		2	85	245	23
500	5438	0	-26.1	4.6	1	77	226	11
700	2920	0	-10.1	4.9	1	76	195	8
850	1398	0	-1.6	3.2	1	68	175	6
1008	* 9		5.0	1.0				

N AMERICA - USA, SHEMYA AFB, AK, 5243N 17406E OB 2

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030								
050								
100								
150								
200								
300	8870	10	-47.3		9	76	266	21
500	5363	6	-25.9	8.7	6	77	272	15
700	2848	6	-10.0	9.1	6	71	276	10
850	1334	6	-3.5	2.9	6	65	265	8
997	* 31		5.7	3.9				

N AMERICA - USA, LONGVIEW, TX., 3221N 09439W OB 2

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030	23785	5	-55.8					
050	20657	4	-60.1		8	57	251	3
100	16427	3	-67.3		5	94	280	16
150	13958	3	-62.6		5	91	284	26
200	12164	3	-57.4		6	94	286	28
300	9515	2	-40.3		4	89	284	18
500	5816	1	-11.8		3	87	290	11
700	3156	1	4.3	11.3	3	68	301	6
850	1550	1	12.0	10.1	3	48	285	4
1006	* 124		12.3	4.5				

N AMERICA - USA, BROWNSVILLE/INT., TX., 2554N 09726W OB 2

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030	23703	8	-53.5		9	91	80	7
050	20687	7	-63.1		9	73	108	4
100	16535	4	-73.3		4	91	288	13
150	14126	3	-65.0		3	88	285	25
200	12329	3	-54.6		3	87	294	27
300	9629	2	-36.1		2	82	290	14
500	5870	1	-8.0		1	57	301	4
700	3174	1	7.8		1	45	22	2
850	1552	1	14.7	9.9	1	25	109	2
1017	* 6		18.8	1.1				

N AMERICA - USA, SAN DIEGO/MONTGOMERY FLD, CA., 3249N 11708W OB 2

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030	23885	9	-56.6		9	42	272	2
050	20678	8	-62.3		8	34	303	2
100	16461	5	-66.9		5	93	260	13
150	13989	5	-62.2		6	95	253	21
200	12190	4	-56.7		4	95	251	26
300	9521	3	-39.2		3	89	248	19
500	5808	0	-11.0		0	73	230	9
700	3139	0	5.8	9.6	0	50	208	5
850	1519	0	15.8		2	18	207	1
1000	* 9		17.4	1.2				

N AMERICA - USA, NASHVILLE/OLD HICKORY, TN, 3615N 08634W OB 2

Pressure (mb)	Height (gpm)	Missing days	Mean (°C)	Dew point depression (°C)	Missing days	Steadiness (%)	Direction (°)	Speed (mps)
030	23924	5	-54.2		6	22	233	1
050	20686	3	-58.0		7	92	244	7
100	16365	2	-61.9		9	98	267	15
150	13845	1	-59.1		7	95	272	22
200	12031	1	-56.6		7	88	280	22
300	9387	1	-42.2		5	82	285	22
500	5730	0	-14.8	10.4	1	82	285	15
700	3105	0	0.0		0	81	285	9
850	1528	0	6.9	10.1	0	70	289	6
1000	* 180		7.7	4.1				

Source: [10].

Figure 8. Monthly long-term, mean, upper-air temperatures and winds.

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Canada (1951-60)													
Aklavik													
mean speed	6.0	5.6	6.5	7.4	7.3	7.8	7.0	7.0	7.0	6.2	5.2	5.7	6.6
prevailing direction	S	S	NW	N	N	N	NW	NW	NW	NW	NW	NW	
Alert													
Mean speed	5.0	5.1	4.6	4.9	5.1	6.5	7.6	6.0	6.4	6.9	5.8	4.6	5.7
prevailing direction	W	W	W	W	WNW	NE	NE	NE	W	W	W	W	
Baker Lake													
mean speed	14.6	14.1	13.5	14.1	14.2	12.0	11.3	12.7	13.6	15.0	14.6	14.8	13.7
prevailing direction	NW	NW	N	N	N	N	N	N	NW	N	N	N	
Cambridge Bay													
mean speed	12.3	10.7	10.6	12.0	12.7	12.9	12.9	12.8	13.4	14.0	12.0	10.8	12.3
prevailing direction	W	W	W	N,NW	NW	N	N	E	E,NW	NW	W	W	
Chesterfield													
mean speed	15.3	14.2	12.9	13.2	14.9	11.8	11.7	13.0	15.2	17.1	14.9	15.6	14.2
prevailing direction	N	N	N	N	N	N	N	N	N	N	NW	N	
Clyde*													
mean speed	4.6	7.4	4.0	4.7	6.4	8.0	8.5	6.4	8.1	10.3	7.0	3.8	6.7
prevailing direction	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	
Coppermine													
mean speed	12.2	10.5	9.2	8.7	8.5	8.5	9.6	10.0	11.0	12.0	11.0	10.3	10.1
prevailing direction	SW	W	SW	W	W	N	NE	NE	N	SW	W	SW	
Coral Harbour													
mean speed	12.1	12.3	10.5	13.1	13.2	12.3	12.2	12.9	13.3	13.3	13.2	13.3	12.6
prevailing direction	NW	N	N	N	NW	N	N	N	N	NW	N	N	
Eureka													
mean speed	7.2	6.6	5.4	5.8	8.4	10.9	11.3	9.6	7.2	6.6	6.2	5.4	7.6
prevailing direction	E	E	E	E	NW	NW	NW	NW	NE	E	E	E	
Frobisher Bay													
mean speed	9.1	9.5	9.7	11.0	13.4	11.7	9.7	8.9	11.5	14.6	12.3	11.0	11.0
prevailing direction	NW	NW	NW	NW	NW	SE	SE	SE	NW	NW	NW	NW	
Holman													
mean speed	9.1	7.9	9.5	11.5	10.3	9.5	8.7	8.9	11.7	13.1	11.6	11.2	10.3
prevailing direction	E	E	E	E	E	E	W	E	E	E	E	E	
Isachsen													
mean speed	10.6	7.9	7.0	7.5	10.3	9.9	10.9	10.0	9.8	11.0	9.0	9.7	9.5
prevailing direction	N	N	N	N	N	N	NW	N,SW	N	N	N	N,NW	
Mould Bay													
mean speed	10.5	8.6	7.9	8.4	11.7	13.0	12.2	11.2	11.6	11.3	9.9	8.5	12.5
prevailing direction	NW	NW	N	N,NW	NW	NW	NW	S,NE	NW	NW	NW	NW	
Nottingham I.													
mean speed	10.9	11.5	9.9	11.5	11.2	10.7	9.8	11.1	10.9	14.5	13.0	11.6	11.4
prevailing direction	NW	NW	NW	NE	NE	NE	W	NE	NW	NW	N	N	

* 2 years only.

Source: [7].

Figure 9. Selected Northern Hemisphere mean surface wind speeds.

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Canada (cont'd)													
Resolute													
mean speed	11.9	11.5	10.4	10.9	11.6	12.6	12.1	12.3	12.5	12.5	11.0	10.4	11.6
prevailing direction	NW	E	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	
Resolution I.													
mean spead	20.5	20.5	16.1	16.2	14.4	13.2	12.5	13.5	13.9	18.2	17.9	20.4	16.4
prevailing direction	W	SW	W	NE	W	NE	E	E	W	W	W	W	
Sachs Harbour													
mean speed	13.2	11.6	10.7	13.2	12.8	12.8	13.1	13.6	14.7	15.2	13.0	12.0	13.0
prevailing direction	N	E	SE	E.SE	E	N.E	NW	SE	E	E	E	E	
Knob Lake													
mean speed	10.1	10.6	10.6	10.0	10.6	10.3	10.2	10.7	12.7	12.5	12.1	11.8	11.0
prevailing direction	NW	NW	NW	NW	NW	SE	NW	NW	NW	NW	NW	NW	
Churchill†													
mean speed	14.0	14.2	13.9	14.4	13.1	12.0	12.3	12.6	14.8	16.1	15.1	16.0	14.0
prevailing direction	NW	NW	NW	NW	N	N	N	NW	N	NW	NW	NW	
Fort Simpson†													
mean speed	6.6	7.8	7.9	8.1	8.0	7.5	7.1	6.8	8.1	7.2	7.8	6.6	7.5
prevailing direction	NW	NW	NW	NW	NW	NW	NW	SE	SE	SE	NW	NW	
Yellowknife†													
mean speed	8.0	9.2	10.7	11.6	10.5	10.4	10.5	10.2	10.4	11.7	9.3	8.6	10.1
prevailing direction	N	E	E	N	E	NE	N	SE	N	E	E	E	
Fort Nelson†													
mean speed	3.9	4.7	5.6	6.5	6.4	6.1	5.0	5.4	5.2	4.8	4.0	3.5	5.1
prevailing direction	S	N	N	N	N	N	S	S	S	S	S	S	
Whitehorse†													
mean speed	8.6	8.8	9.1	8.7	8.7	8.0	7.4	7.8	9.1	10.4	9.0	8.7	8.7
prevailing direction	S	S	S	S	SE	SE	SE	SE	S.SE	S	S	S	
Alaska													
Anchorage													
mean speed (31)**	5.2	5.9	5.8	5.7	6.4	6.2	5.6	5.2	5.2	5.3	5.1	4.9	5.5
prevailing direction (8)	NE	N	N	N	S	S	S	NW	NNE	N	N	NE	N
fastest mile (10)	60	62	49	66	31	33	32	45	49	59	66	56	66
direction (10)	NE	S	N	S	S	S	S	S	SE	S	NE	SW	NE
Barrow													
mean speed (30)	11.0	11.3	10.9	11.5	11.8	11.4	11.8	12.7	13.7	14.0	12.5	10.9	12.0
prevailing direction (7)	ESE	ENE	NE	E	NE	E	SW	E	ENE	NE	NE	ENE	NE
fastest mile (30)	56	51	48	52	43	38	41	47	56	51	63	70	70
direction (9)	E	SW			SW	W		E	W		W	W	W
Barter I.													
mean speed (7)	14.7	15.2	11.7	12.7	11.9	11.0	10.3	11.0	12.8	14.7	14.9	11.9	12.7
prevailing direction (7)	W	W	W	ENE	E	ENE	ENE	E	E	E	ENE	ENE	ENE

* Average values 1954-62;[127] prevailing direction.[6]

† Periods prior to 1951-60.[6]

** Number of years of record.

Figure 9. Continued.

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Alaska (cont'd)													
Fairbanks													
mean speed (27)	3.2	3.8	4.7	5.9	6.8	6.4	5.8	5.7	5.5	4.9	3.7	3.0	5.0
prevailing direction (8)	N	N	N	N	N	SW	SW	N	N	N	N	N	N
fastest mile (11)	41	57	60	55	42	40	50	34	49	50	50	34	60
direction (11)	SW	W	SW	SW	SE	SW	SW	W	SW	SW	SW	E	SW
Kotzebue													
mean speed (13)	15.3	14.3	13.2	13.4	10.3	12.2	12.9	13.9	13.0	13.6	13.9	12.9	13.3
prevailing direction (14)	E	E	E	ESE	W	W	W	W	ESE	NE	ESE	NE	W
McGrath													
mean speed (8)	2.7	3.5	4.0	5.0	5.6	5.7	5.4	5.1	4.9	3.8	2.5	2.4	4.2
prevailing direction (9)	NW	NW	NW	N	E	S	S	S	N	N	ESE	NW	NW
Nome													
mean speed (10)	12.0	11.1	11.2	10.9	10.0	9.5	9.9	10.7	11.4	10.9	11.6	9.8	10.8
prevailing direction (9)	E	ENE	E	ENE	NE	SW	WSW	SW	N	NE	N	E	E
fastest mile (10)	75	74	72	53	68	40	38	50	57	57	73	72	75
direction (10)	E	W	NE	S	NE	E	SE	SW	E	SE	SW	E	E
Greenland													
Thule													
mean speed (11)	9	9	7	7	7	7	7	6	8	10	9	8	8
prevailing direction (11)	E	E	E	E	E,W	W	W	W	E	E	E	E	E
Eismitte													
mean speed (2)	11	9	13	12	9	9	9	8	11	10	9	14	10
Angmagssalik													
mean speed (30)	6	6	5	3	3	3	3	3	3	4	5	5	4
Scoresbysund													
mean speed (12)	5	5	4	4	3	3	3	3	3	4	4	4	4
Nanortalik													
mean speed (41)	12	11	11	10	7	10	7	8	8	9	10	10	10
Eurasia													
Jan Mayen													
mean speed (mph)	21	21	18	17	13	14	12	14	16	18	19	18	17
no. of days with gales*													
Vardo													
mean speed (28)	22	21	21	19	16	16	13	14	17	19	21	21	18
no. of days with gales*(28)	5	5	4	3	2	1	1	2	2	3	5	5	38
Ostrov Diksona													
mean speed (19)	19	19	16	17	16	16	15	16	17	16	18	17	17
no. of days with gales*(19)	11	19	8	7	5	3	1	3	5	6	9	8	75
Bukhta Tikhaya													
mean speed (10)	16	15	12	12	11	10	8	9	13	15	15	17	13
no. of days with gales*(10)	10	9	7	5	3	3	2	2	4	6	8	11	69

* Gale defined as: windspeed $\geq$ 32 mph.

Figure 9. Concluded.

probability of having winds sufficiently low for inflation without waiting for an extended period.

Once inflated and on the tower, the mean wind speed ceases to be crucial and emphasis shifts to the maximum wind speed. Maximum winds, both on the surface and at altitude, are important for aerostat system survival. At altitude they determine the maximum pressure which must be maintained in the hull to prevent collapse of the nose (nose cupping), and they determine the break strength required in the tether to restrain the aerostat. On the surface they determine how rugged the mooring system must be. While the mean surface winds are quite reasonable at most locations in the North, peak winds can be excessive.

Peak surface gusts of 207 mph have been recorded at Thule, Greenland [6], and mean surface wind speeds of 120 mph have been recorded over a 24 h period on Mount Washington in New Hampshire [6]. While this record Thule surface wind has the potential to destroy a moored aerostat, it is not clear that it would adversely affect an aerostat on station. Figure 8 is a sample of monthly, long-term, mean upper air wind speed data in the area of interest. Review of data for the entire year does not indicate that the normally prevailing wind conditions at altitude are a significant problem for aerostat operations if the correct site is selected. This does not preclude the possibility, however, of peak gusts at altitudes that have not been recorded, since the sampling data is sparse at best.

Air Force operations in the Florida Keys have gained considerable experience with surface winds well in excess of the surface winds indicated in Fig. 9. These systems were designed for a high peak wind environment. More than one episode of winds approaching 90 kn has been recorded during hurricane passage in the Keys with minimal or no damage to moored aerostats [3]. In stationing an aerostat system in the North, analysis of historical meteorological data would be crucial to success.

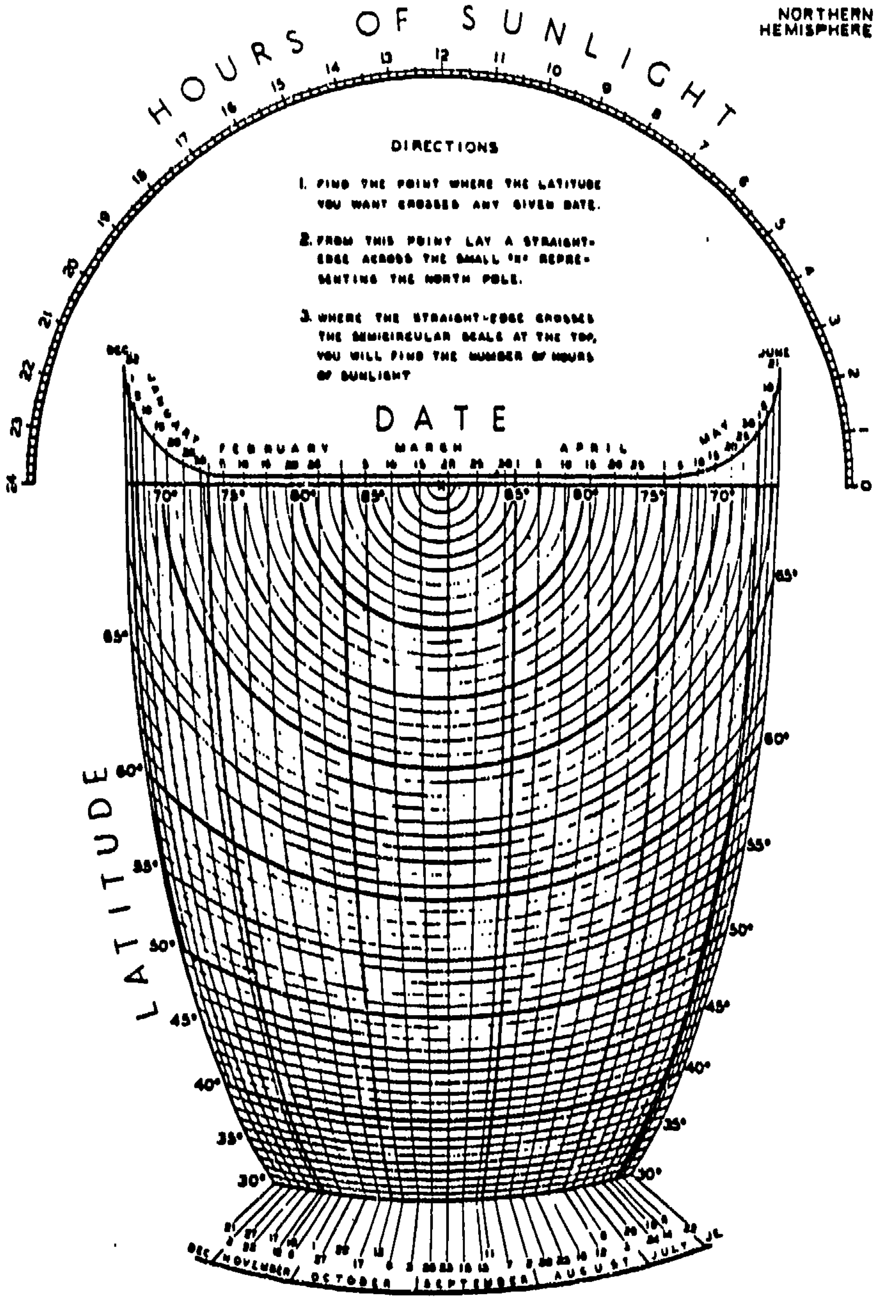
DAYLIGHT AND OBSTRUCTIONS TO VISIBILITY

Figures 10 and 11 are nomographs that enable the calculation of the amount of daily sunlight and twilight respectively, as a function of latitude. As can be seen, at the latitudes of interest for this report, the phenomena of continual darkness or daylight is not applicable. Since aerostat operations at all current sites are conducted around the clock, with site lighting utilized for night operations, the amount of light is not really a factor except from the standpoint of morale. There is no daylight problem in the latitude range of 50° to 65°.

Figure 12 provides information on the average number of days of fog at several typical locations in the arctic region. While this does provide some indication of its potential impact on aerostat operations, it does not take into account the artificial formation of ice fog which is formed from the freezing condensation of vehicle and generator exhausts at temperatures of -22°F or colder [8]. In addition, while fog is usually not formed in the presence of wind, advection fog can be a problem. The famous Aleutian fog can persist even with winds that reach 35 kn [8]. Aerostats have been successfully operated in fog in Florida and the Bahamas; however, these cases are not fully representative of the types of fog found in the latitude regions of interest.

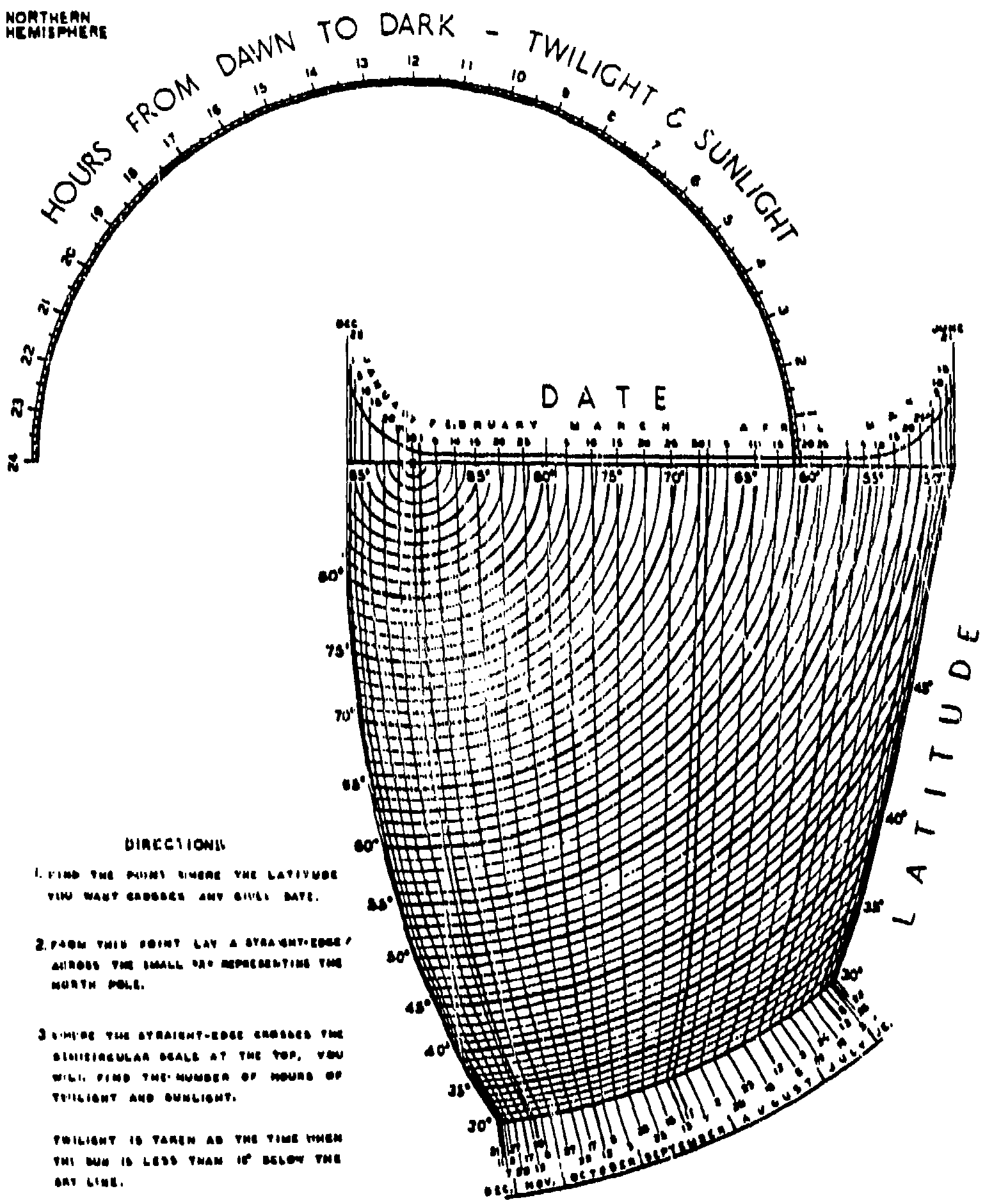
PRECIPITATION AS SNOW

Snowfall decreases as latitude increases, and average annual snowfall in the Arctic is quite small except at coastal locations [7]. Precipitation as snow varies significantly over the region of interest. Convective, cyclonic, and orographic precipitation are all possible; however, convective precipitation is insignificant with respect to cyclonic and orographic amounts. Along the coast of Greenland and Canada, in the area of the Davis Straits, very high annual snowfalls are reported, with mean amounts as high as 400 cm[11]. Over the arctic area as a whole, in areas not affected by a concentration of cyclonic and orographic forces, average precipitation as snow is quite low, averaging 5 to 10 in. per year [7], and decreases with



Source: [7].

Figure 10. Northern Hemisphere sunlight nomograph.



Source: [7].

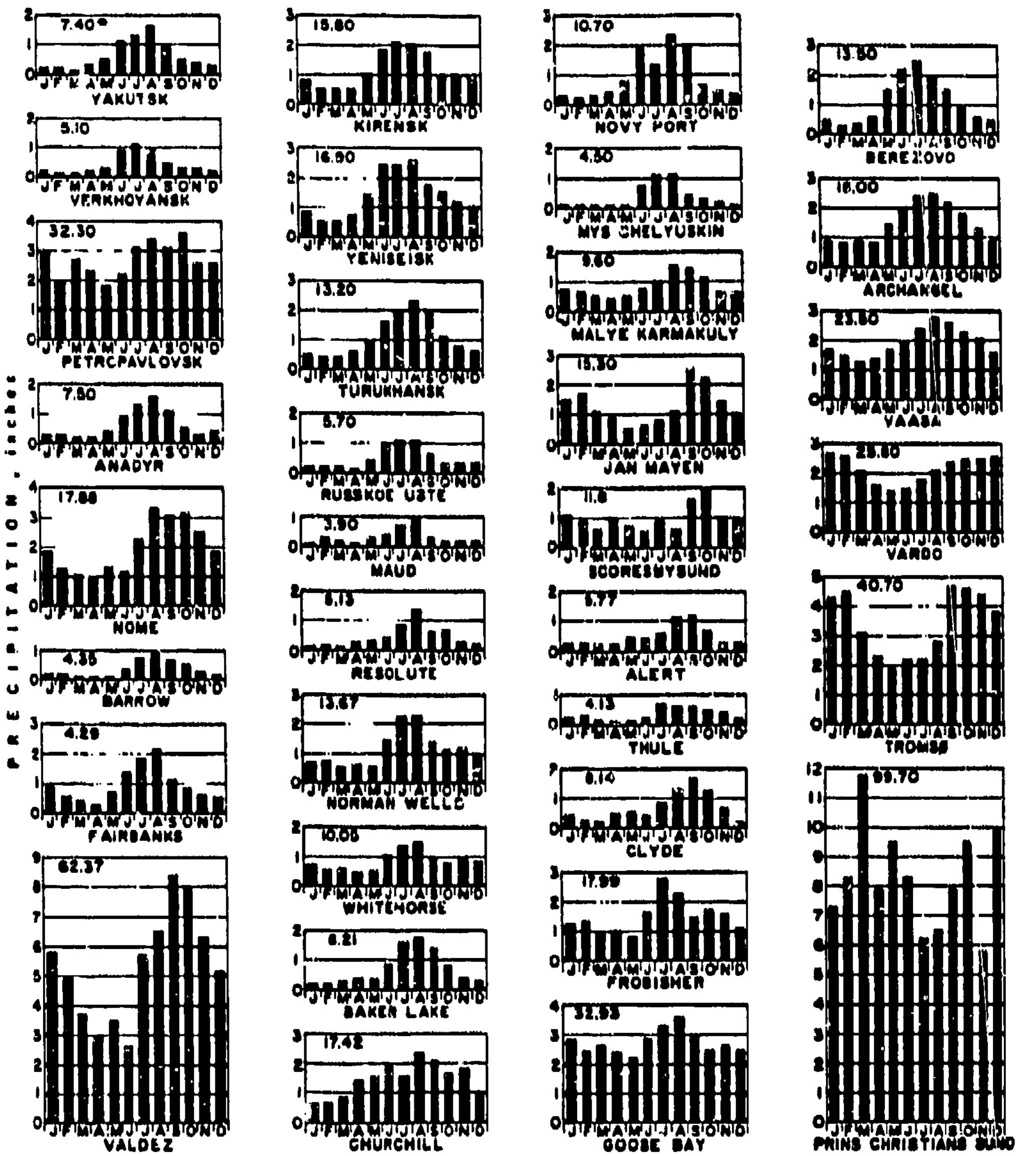
Figure 11. Northern Hemisphere sun and twilight nomograph.

PLACE	JAN.	MAR.	MAY	JULY	SEPT.	NOV.	ANNUAL
Dikson Island	5.5	7.9	4.9	22.9	10.5	5.2	152.2
Kola	0.7	0.2	1.0	3.1	1.9	1.6	16.1
Tiksi Bay	3.7	4.4	5.3	9.0	4.6	1.0	66.1
Verkhoyansk	3.4	0.6	0.6	1.5	4.1	1.8	25.9
Wrangel	1.6	4.6	12.2	21.4	10.8	3.8	113.5
Yugor Strait	4.5	6.2	9.1	19.6	14.1	4.5	123.8
Aklavik	19.6	27.6	2.0	2.2	21.2	15.6	165.6
Tromsø	1.0	0.8	1.0	2.0	2.0	1.0	14.0
Vardo	0.0	0.0	1.0	6.0	1.0	0.0	18.0
Green Harbor	0.1	0.1	0.4	4.0	1.0	0.0	13.0
Bear Island	1.1	2.7	6.7	18.7	12.0	3.3	82.0
Jan Mayen	1.9	3.2	3.3	12.8	5.9	1.8	58.3
Angmagssalik	1.0	1.0	7.0	9.0	4.0	2.0	48.0
Godhavn	9.0	11.0	15.0	17.0	8.0	3.0	127.0
Godthaab	1.0	1.0	7.0	13.0	7.0	1.0	61.0
Ivigtut	0.2	0.4	2.0	6.0	3.0	1.0	26.0
Upernavik	2.0	2.0	5.0	11.0	2.0	1.0	47.0
Churchill	1.0	*	1.0	2.0	1.0	*	13.0
Craig Harbour	*	1.0	0.0	2.0	1.0	*	9.0
Lake Harbour	2.0	1.0	2.0	5.0	2.0	3.0	30.0
Pond Inlet	1.0	*	*	*	*	2.0	9.0
Dutch Harbor	0.9	0.9	2.5	3.5	1.8	0.0	18.4
Fairbanks	17.2	11.6	0.8	2.4	3.2	6.1	68.0
Nome	5.3	5.2	5.0	8.1	4.4	3.2	67.2
Point Barrow	5.0	2.3	7.5	15.0	5.4	2.7	82.6
St. Paul's Island	1.7	2.8	6.9	7.0	2.8	1.5	52.2

*Less than one day

Source: [7].

Figure 12. Average days with fog.



* Annual total precipitation in inches.

Source: [7].

Figure 13. Mean monthly precipitation at selected stations.

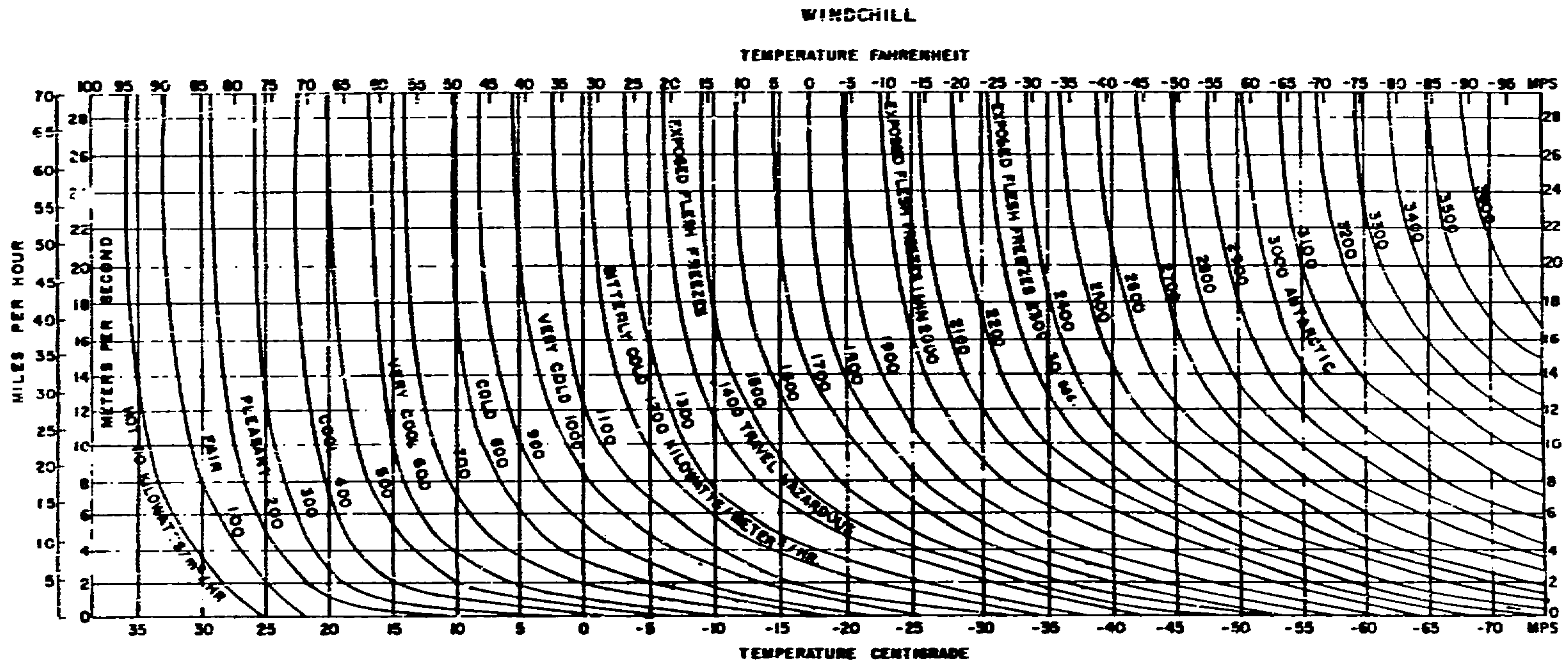
northward movement. Figure 13 indicates the mean monthly and annual precipitation for several sites in the northern region of interest.

Since snow will have a significant effect on aerostat operations, picking a site with sufficiently benign meteorological conditions is well worth the work. The U.S. Navy's *Marine Climatic Atlas of the World* supplies historical information on cyclonic tracks mapped by the month.

WINDCHILL

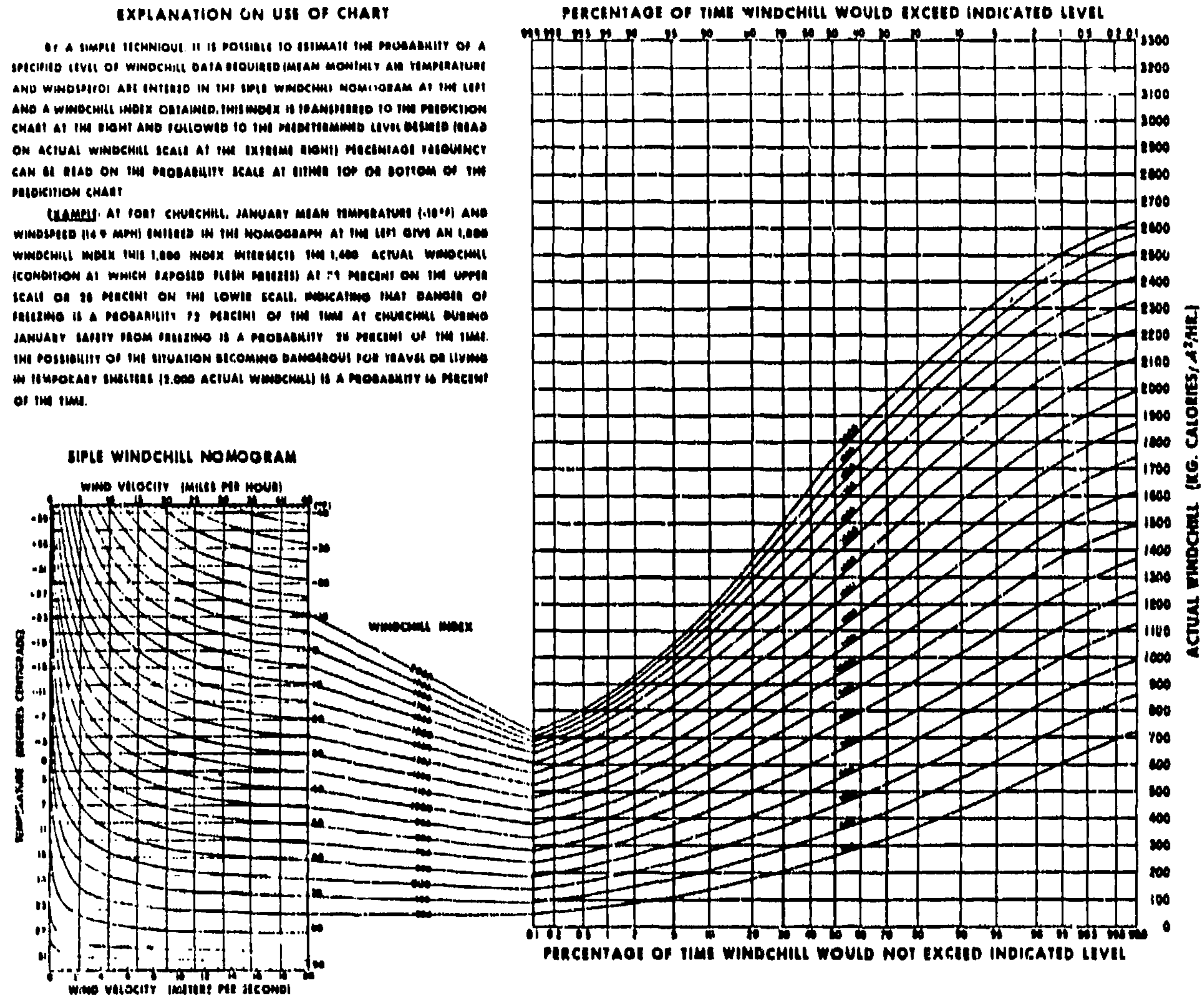
Windchill is the measure of the combined effect of temperature and wind to remove heat from an object by convective cooling. Convective cooling calculations for equipment are straightforward and would be a normal part of a system design to determine how much insulation to install, which lubricants to use, etc. The calculations for the human body are not as simple since heat output is not constant over time, is related to exertion, and is peculiar to the part of the body that is exposed [8].

The winds and temperatures previously described give rise to windchill factors which can cause freezing of exposed flesh in a matter of seconds during extreme weather excursions. Figure 14 provides an indication of how rapidly this can occur. At a temperature of -60°F with a wind of 10 kn, or a temperature of -25°F and 30 kn of wind, the exposed flesh will freeze in 30 to 60 s. Even for relatively mild temperatures (for these areas) of +10°F, the flesh will freeze with surface winds of 30 kn. The probability of encountering a given windchill condition may be estimated using the nomograph of Fig. 15 and the mean temperature and wind speed data for the particular area of interest.



Source: [7].

Figure 14. Windchill nomograph.



Source: [7].

Figure 15. Windchill prediction nomograph.

III. ENVIRONMENTAL PREDICTION ASSISTANCE

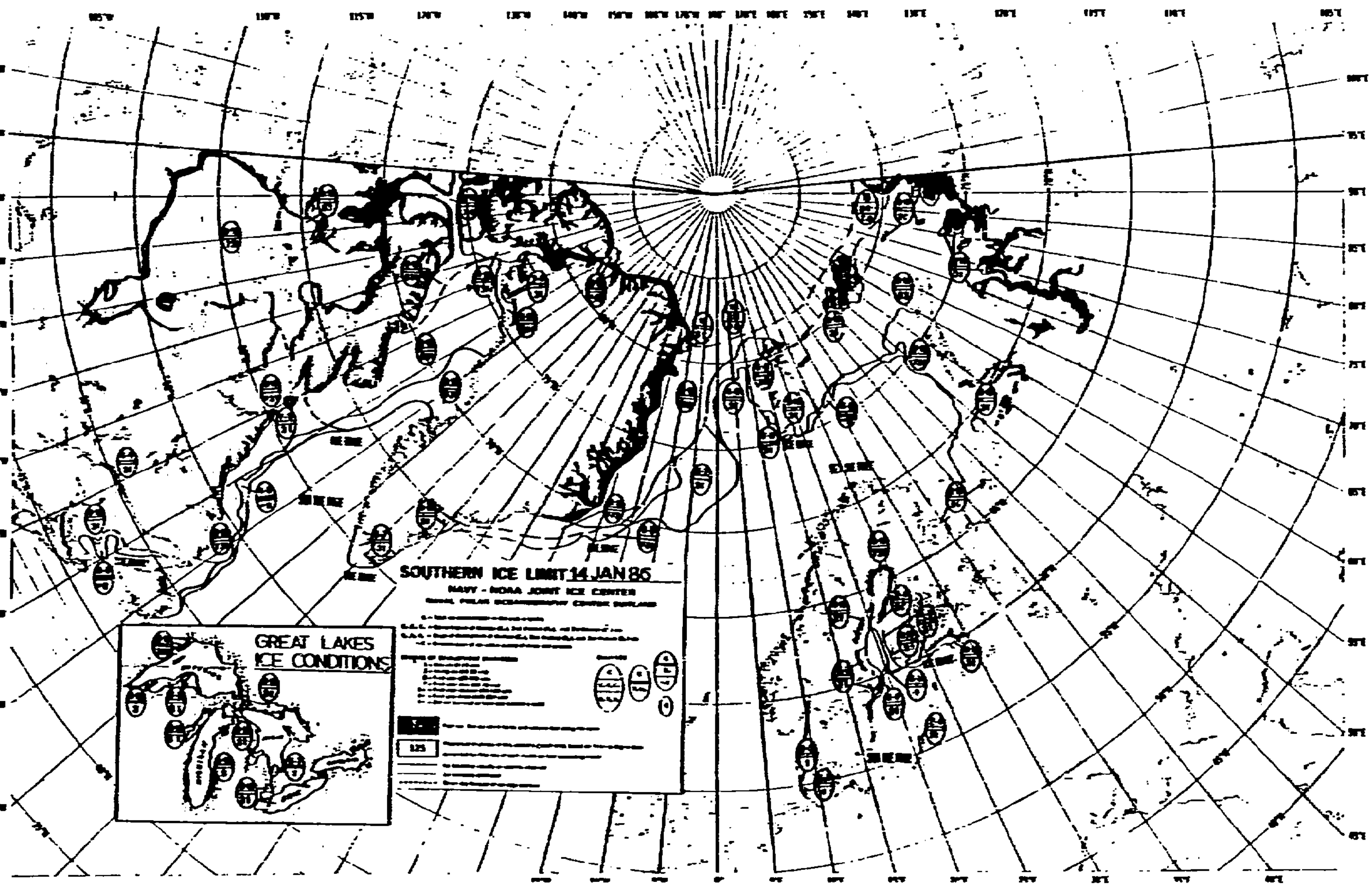
With the extreme variability of weather in the northern latitudes, historical and predictive meteorological information will be very important for selecting an aerostat site. Historical wind velocities, temperatures, and snowfall levels will be required for any site, as well as sea ice formation data for ship- or barge-based operations.

In addition to the predictive resources and historical climatic data of the U.S. National Oceanic and Atmospheric Administration (NOAA), USAFETAC and the U.S. Naval Oceanography Command provide specific, peculiar data necessary for planning aerostat operations in the North. And, as mentioned above, the Navy's *Marine Climatic Atlas of the World* supplies historical information on cyclonic tracks mapped by the month.

The USAFETA is one of the best sources for historical weather data for land-based operations at northern military sites. It collects, stores and can retrieve data on the aerospace natural environment. It also evaluates and adapts techniques for application of these data in military weapons systems development and operation.

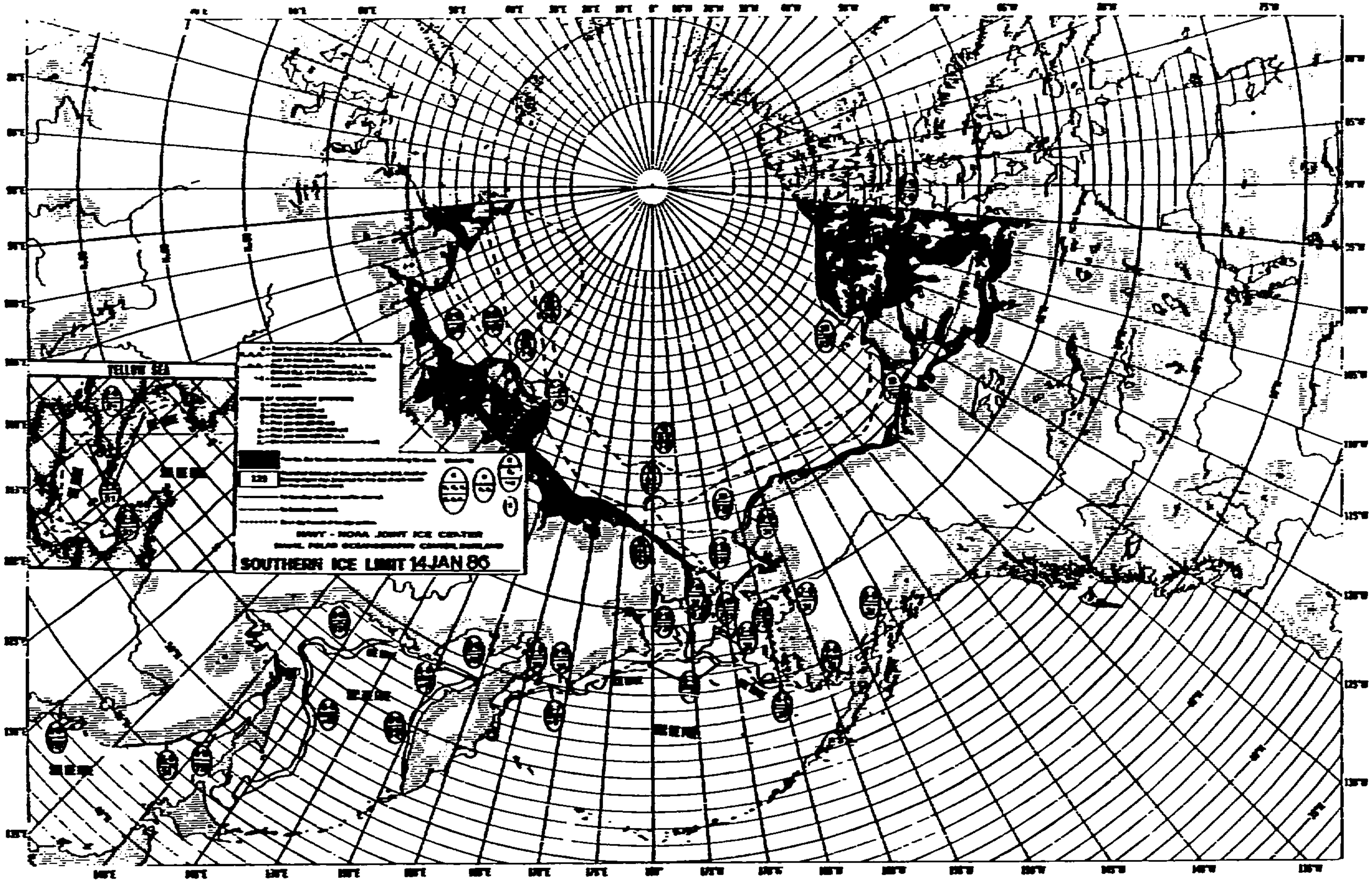
The U.S. Navy Oceanography Command information is related to sea ice formations and is necessary for sea-based operations. For the area of interest to this report, the Navy information is broken into two broad areas: Arctic East and Arctic West.

Figures 16 through 19 depict the predicted southern limit of the ice edge, in summer and winter, for the Arctic East and West reporting regions [12]. The "ice edge" referred to does not mean the edge of a solid sheet of ice from the ice edge back to the pole, but rather the edge of the southern extent of the excursion of any detected free floating ice. Figures 16 and 17 show the ice edge for the winter months, while Figs. 18 and 19 are for the summer months. These charts provide information on the total concentration of ice in the area, the concentration of the 1st, 2nd, and 3rd thickest ice, and the stages of development of each of them. This data is obtained from both satellite and on-site sensors and is updated weekly.



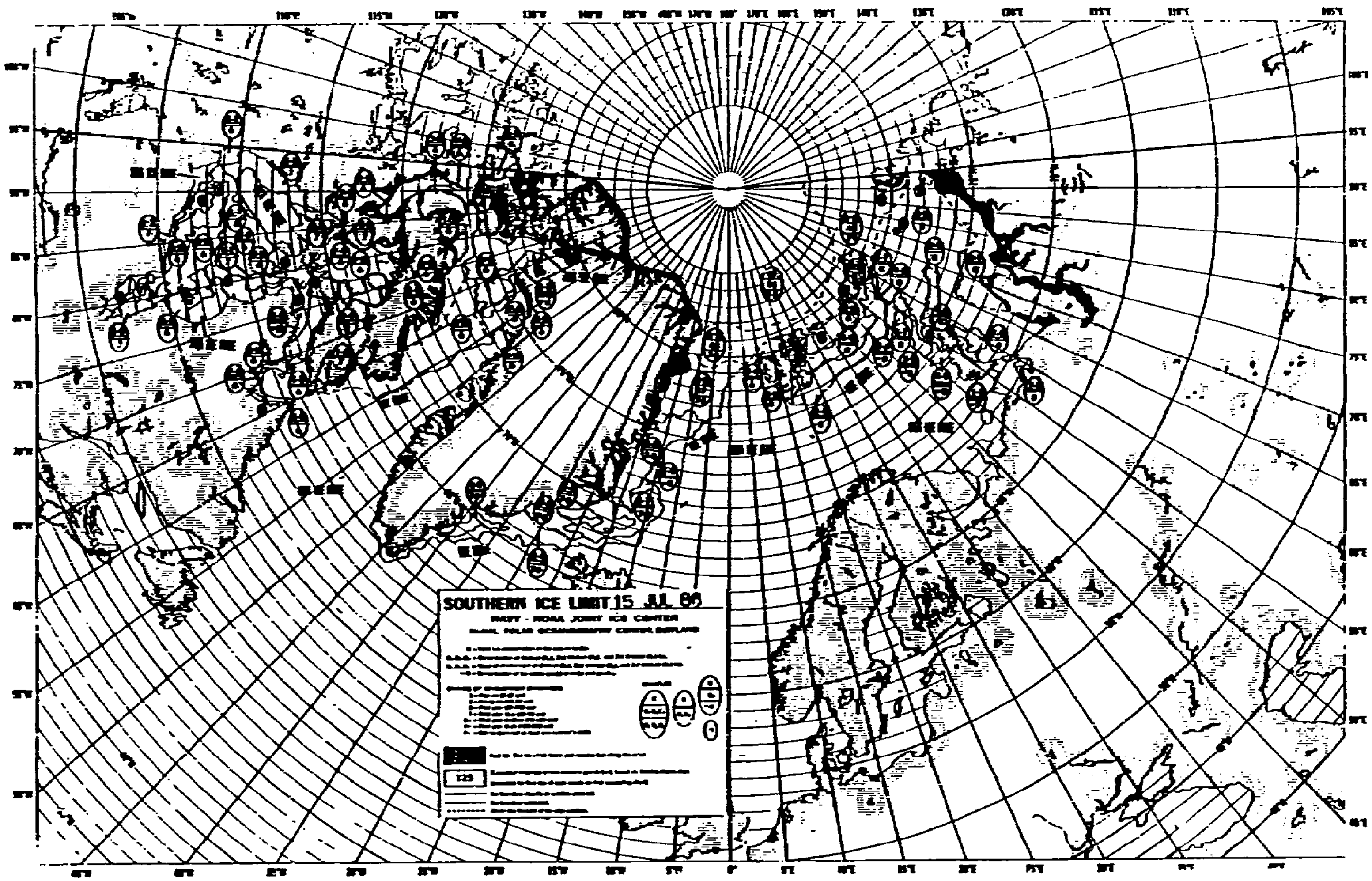
Source: [12].

Figure 16. Winter southern ice edge limit--East.



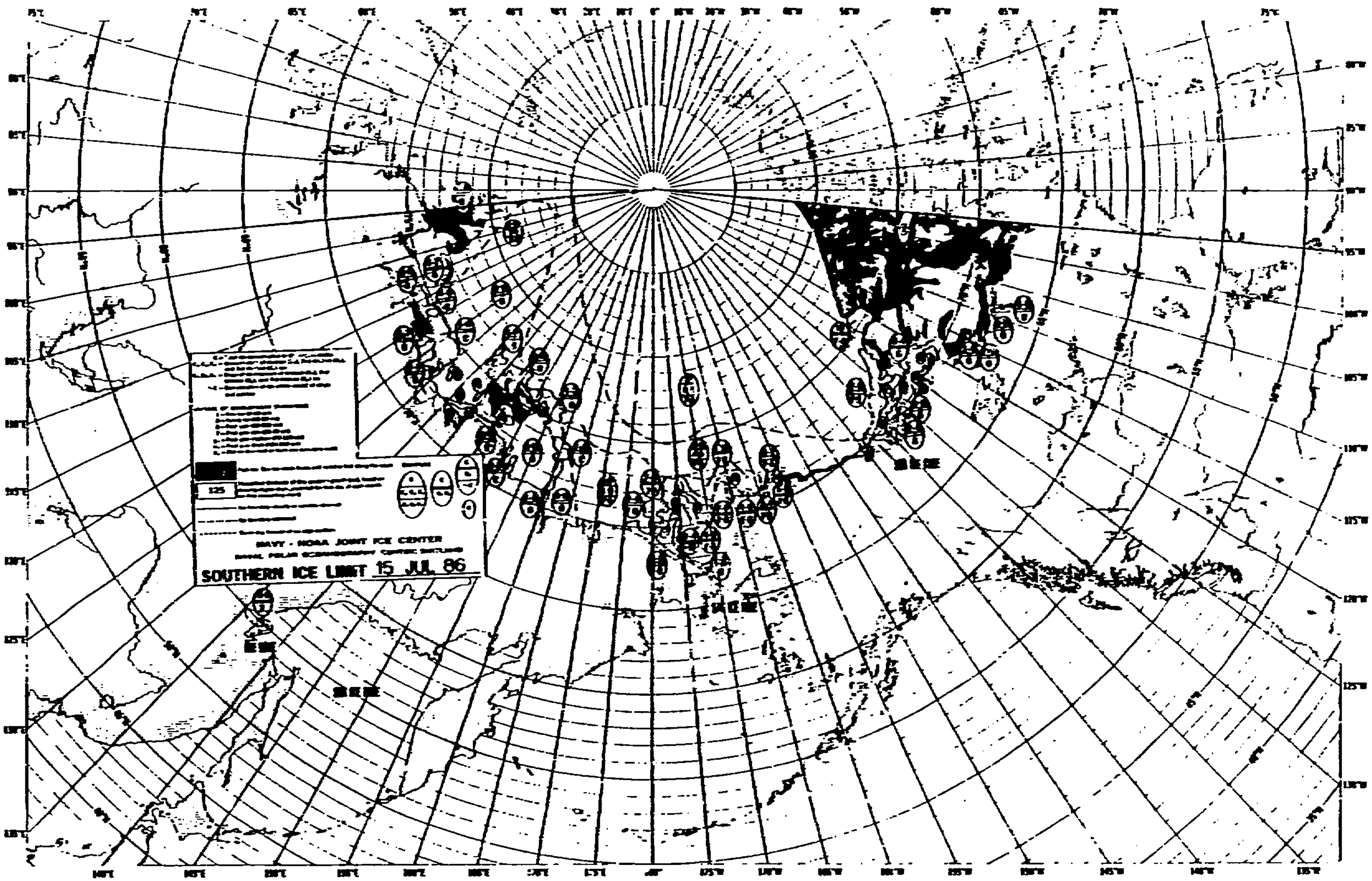
Source: [12].

Figure 17. Winter southern ice edge limit--West.



Source: [12].

Figure 18. Summer southern ice edge limit--East.



Source: [12].

Figure 19. Summer southern ice edge limit--West.

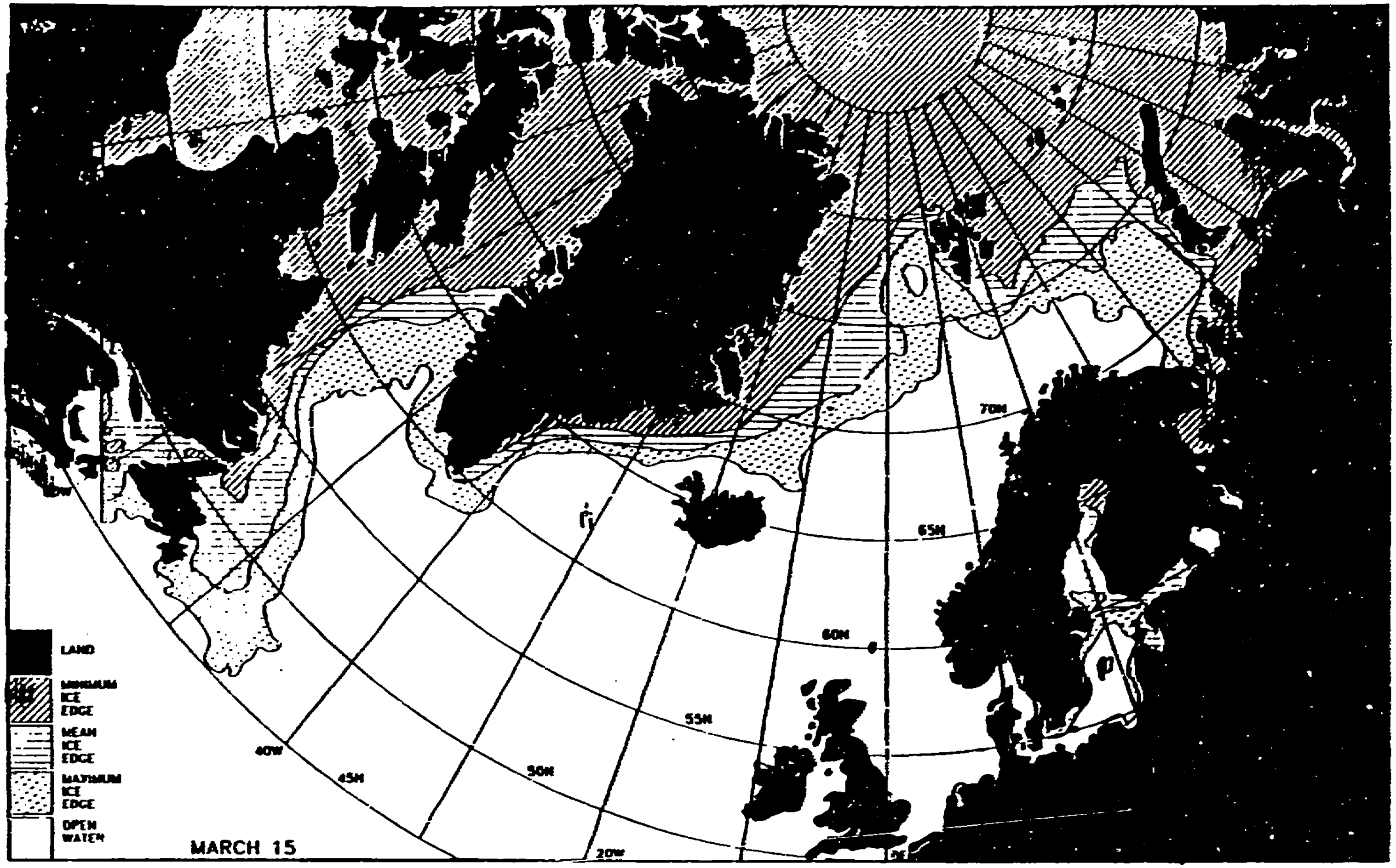
Figures 20 through 23 depict the extent of ice edge movement, the predicted mean ice concentration, the probability of *any* ice, and the mean ice concentration when ice is present for the Arctic East [13]. This information is also available for Arctic West [14]. The first of these charts is useful to see the variability of ice edge movement. However, it is the latter three that are most useful in determining whether a specific location may be usable for a sea-based aerostat system, at specific periods during the year for operational planning.

By using the latter three charts together, planning data can be obtained. Figure 24 depicts a possible ship route which could be a route for an aerostat barge [14]. Interpretation of this data is provided in the *Sea Ice Climate Atlas* as follows:

> Interpretation of the charts in this Atlas should be straightforward. A possible conflict may arise if one tries to reconcile the terminology "ice edge" with the depiction of the shaded area. The shaded presentation was chosen in lieu of simpler isopleth display to minimize the chance for false interpretation of the data. This is because a label on an isopleth does not explicitly define the conditions on either side of the line. The slope of the gradient is not so clearly obvious as it is on a topographic map of the Earth's surface. This is compounded by the fact that the presence of sea ice is discontinuous in nature and whereby regions of 80 percent mean ice concentrations may be bordering regions of 20 percent ice concentrations with no intermediate region of 50 percent ice concentration. Shading provides an unequivocal sense of direction to the slope of the gradient which is quite necessary for correct interpretation, especially during the spring and summer seasons.
>
> An alternate way of thinking about the meaning of a particular shaded area is to refer directly to the definitions given above. Using these, one can interpret the shaded areas of Minimum Ice Edge as being an aggregation of grid cells which always contained ice over the composite period. The shaded area that falls between the Mean Ice Edge and the Minimum Ice Edge are all those cells that contained ice at least half of the composite period. Likewise, the shaded area between the Mean Ice Edge and the Maximum Ice Edge represents all those cells that contained ice at least once in the composite period but not more than half of the composite period. Interpretations of the other shading classifications can be made in a similar manner.
>
> Experience has shown that when sea ice occurs in a particular area it almost always occurs in high concentrations. For this reason the Mean Ice Concentration When Ice is Present summary was developed. Because the Mean Ice Concentration summary treats

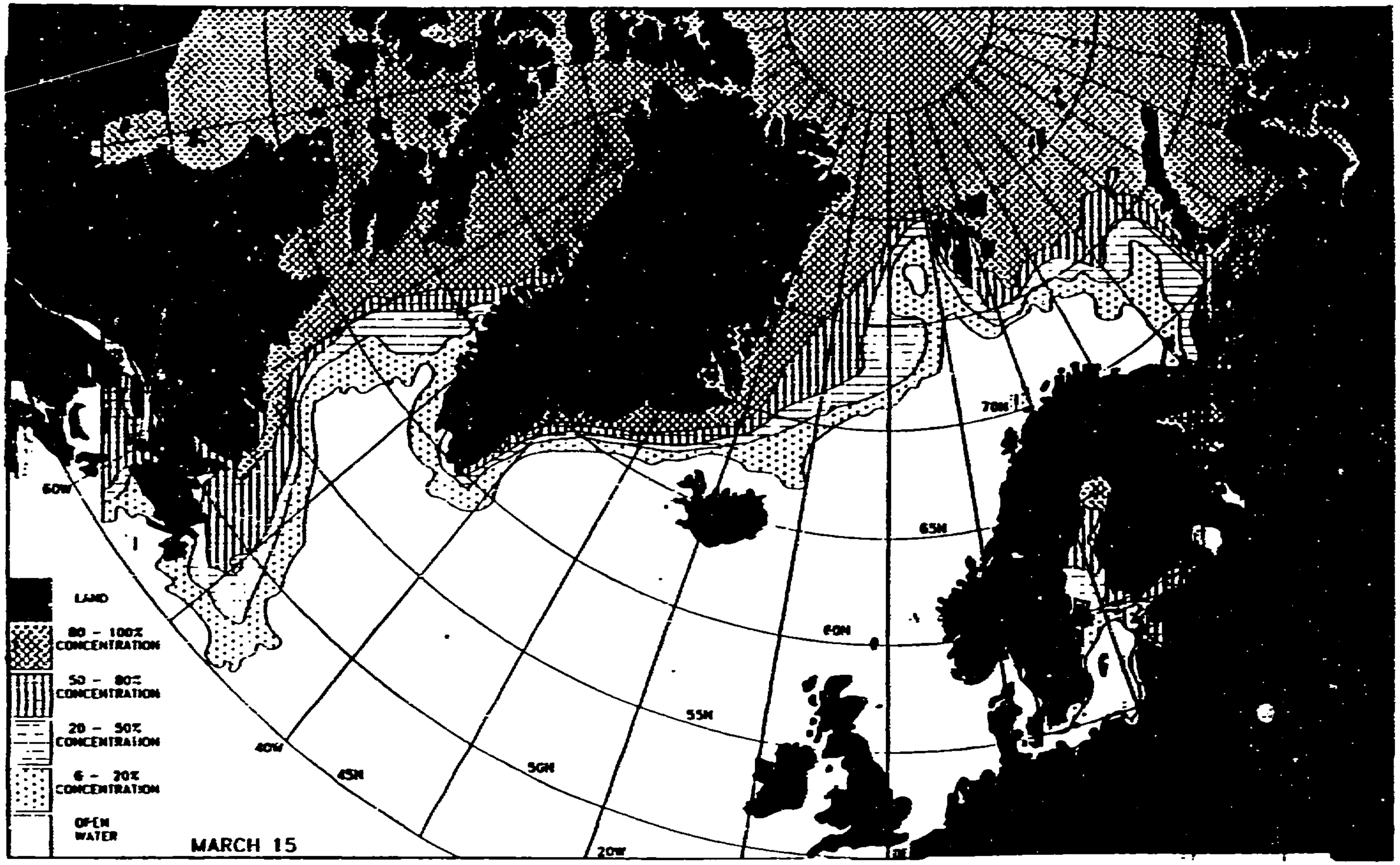
instances of no ice occurrence as zero ice concentration the summary may present misleadingly low concentration values as compared with the ice concentrations actually encountered. Figures 24a*, b, and c illustrate a case in point. A vessel planning on penetrating the ice pack to the Antarctic continent along the route indicated would expect to encounter ice of 0 tenths to 2 tenths concentration based on the Mean Ice Concentration, Figure 24a. Examining the Probability of Occurrence of Any Ice, Figure 24b, and the Mean Ice Concentration When Ice is Present, Figure 24c, it is apparent that there is a 0 percent to 20 percent probability of encountering ice but that if encountered, it will be 2 tenths to 6 tenths concentration. For ships that are not icebreakers but are merely ice reinforced or not reinforced at all the difference in expected ice concentration may make a significant difference in the planning and the eventual outcome of the voyage.

*Figure references have been changed to correspond with this report.



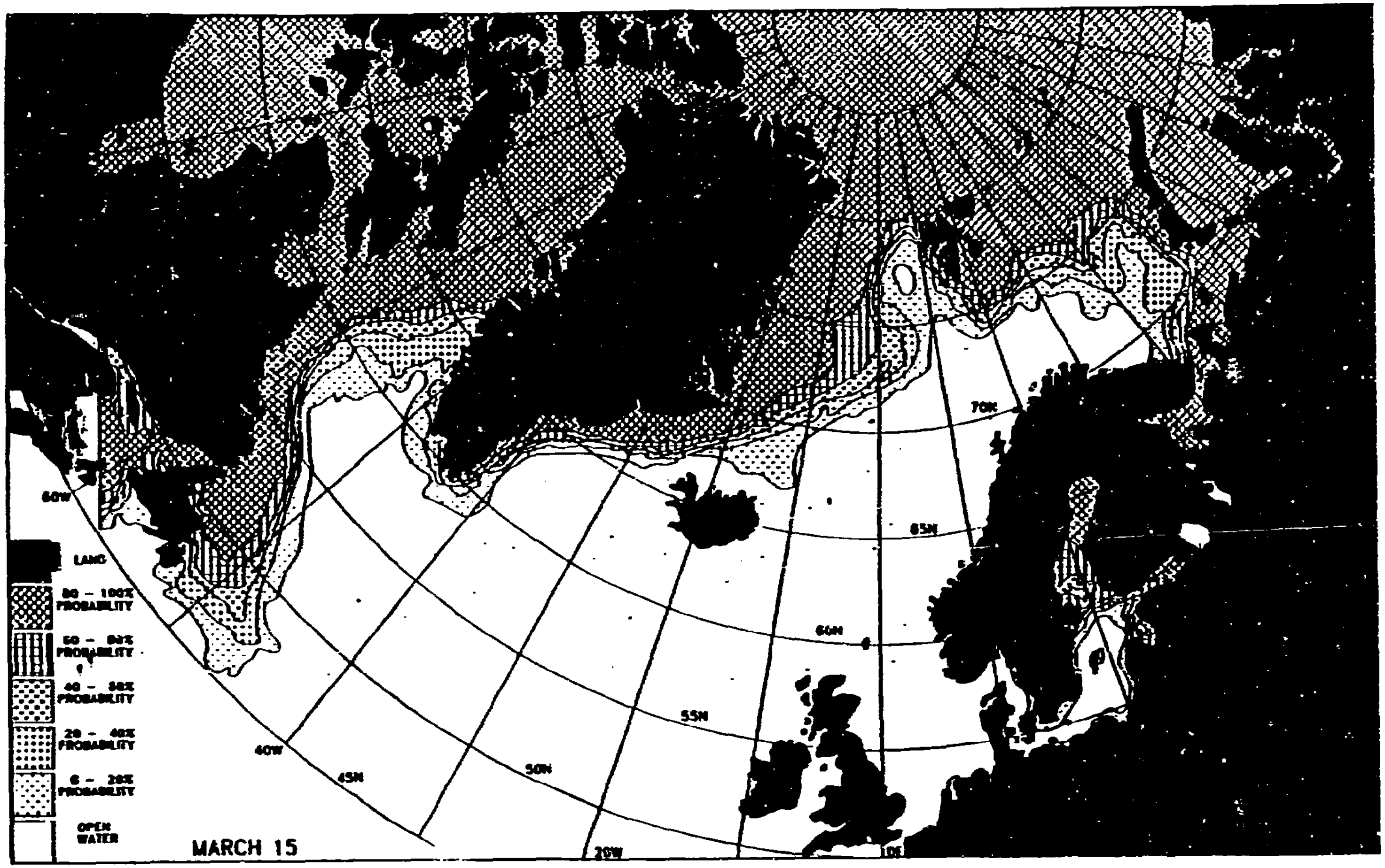
Source: [13].

Figure 20. Maximum - mean - minimum ice edges--East.



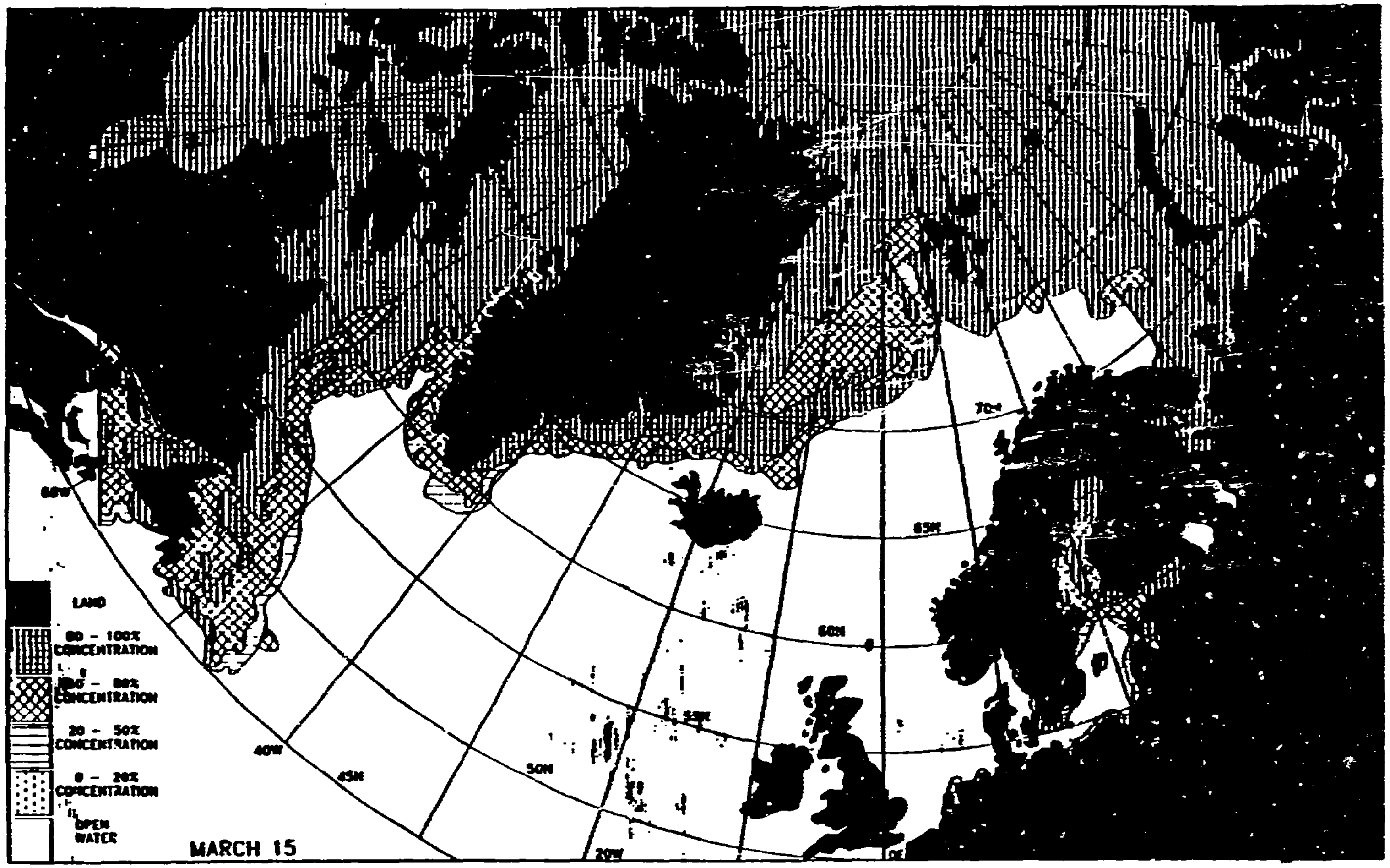
Source: [13].

Figure 21. Mean ice concentration--East.



Source: [13].

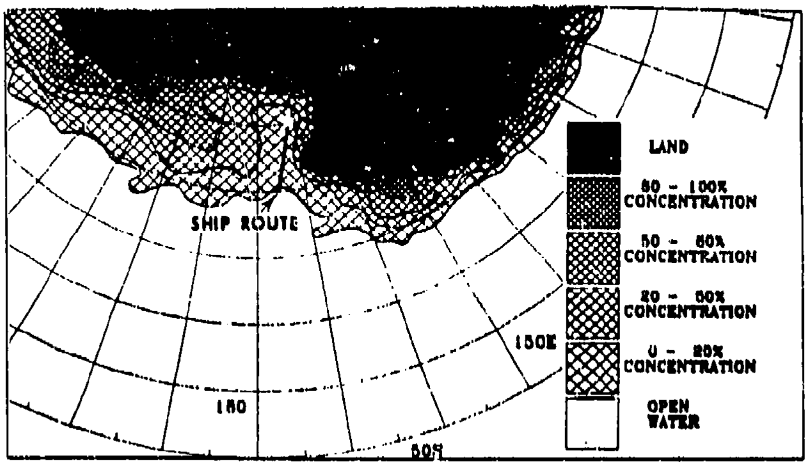
Figure 22. Percent probability of occurrence of any ice--E[illegible]t.



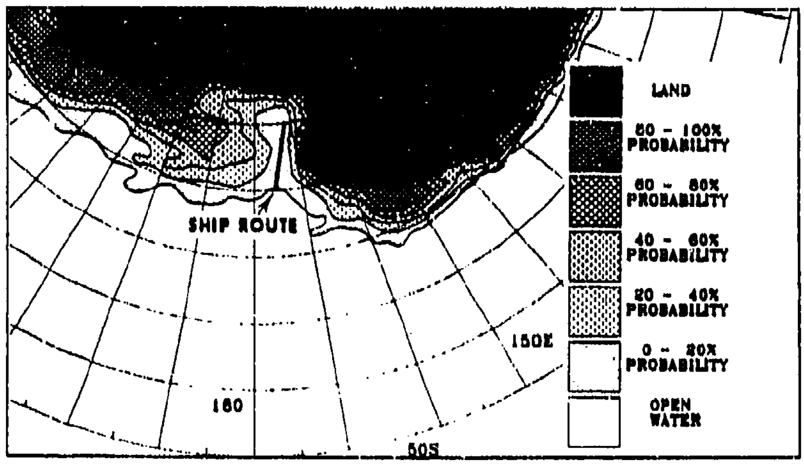
Source: [13].

Figure 23. Mean ice concentration when ice is present--East.

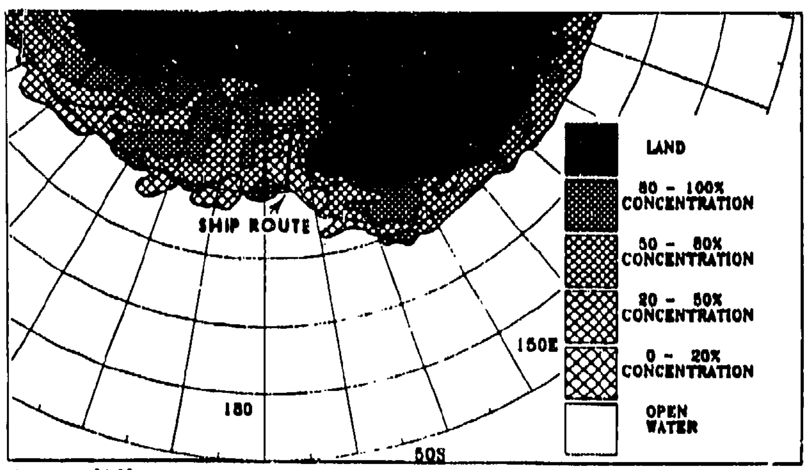
a. Mean ice concentration.



b. Probability of occurrence of any ice.



c. Mean ice concentration when ice is present.



Source: [14].

Figure 24. Ice data.

IV. PRIOR COLD WEATHER AEROSTAT TESTING

Prior documented cold weather aerostat testing is limited to one testing period conducted by AFGL. This testing period has been reported in several documents [4,11,15], but they only cover the one test sequence and are redundant. These tests were conducted in conditions which should provide considerable insight into the problems to be faced. Unfortunately, no follow on program was conducted aimed at finding solutions to problem areas discovered in the initial testing, although solutions were postulated for some of these areas.

While the aerostat used for this testing was considerably smaller than a potential arctic ASET, the problems faced are very similar, differing primarily with regard to exposure duration and component size. Where applicable, the lessons learned have been incorporated into the specific areas addressed by this report.

V. OPERATIONAL SYSTEM IMPACTS

Table 1 summarizes the major weather differences faced by aerostat systems operated in the North. The impact on system operation due to the environment previously described is primarily limited to those parts of the system which must function outside of a controlled environment. By designing much of the system to operate within enclosures, and by insulating and heating these enclosures, the components inside may be isolated from weather extremes.

There is a body of knowledge, resident in the companies and commands which operate in the extreme latitudes, which can be brought to bear on the engineering problems to be encountered. The Engineering Manual for McMurdo Station [16], for example, acts as a corporate memory for the Naval Civil Engineering Corps for operations in Antarctica and addresses a wide variety of subjects including the building and maintenance of runways, roads, buildings, power distribution systems, and ship offloading facilities.

TABLE 1. Weather Impacts on System Operation.

	Current System	Northern System
Wind - moored		
Average	6-10	8-12
Peak	70+	70+
Wind - at altitude		
Max	40-60	60-100
Fog	Occasional	10-60 days
Temperature	25°-115°F	-60° to 80°F
Snow/whiteout	Light	Heavy
Icing	Light	Potentially heavy

AEROSTAT SUBSYSTEM

An aerostat is composed of two principal components: (1) the bag and rigging and (2) everything else. Tables 2 through 5 identify the components of concern.

The bag is a laminated fabric composed of three to four layers. The outer layer may be a coated polyurethane or Tedlar, and is optimized for ultraviolet protection. The middle layer is the strength member and provides the principal bulk and weight. The inner layer acts as a helium permeation barrier and is optimized for this purpose. In those parts of the aerostat which do not contain helium, such as the tail, this barrier is not present.

The rigging consists of the flying confluence lines, the mooring confluence lines, the closehaul lines, the tailfin guy lines, and the nose probe lines. In addition, there will be load lines from the load curtains within the aerostat to carry any internal payload. These latter lines, however, can be ignored for this report as no internal loads are anticipated. Also, they are inside the aerostat and thus protected from all meteorological hazards except temperature.

The "everything else" referred to consists of blower motor assemblies, instrumentation and control packages, helium and air valves, meteorological instrumentation, and strobe lights--all attached to the outside of the hull and thus exposed to the elements. The hazards to the aerostat subsystem consist of snow accumulation on the hull and fins [4]; ice jamming of the anemometer, fan motor inlets, and valves [4]; ice accumulation on the guys and rigging [11]; and cold temperature extremes for the entire system [14].

Repair of a rip in the fabric of an aerostat is normally a very simple procedure. For aerostat materials using Tedlar as an outer laminate, special methods and care are required to ensure that the repair provides the proper strength and life. The temperatures encountered in the North only aggravate this problem. Repair of Tedlar materials has been accomplished once in cold climates [4], but still remains an issue to be validated.

There is no specific hazard which would preclude operation of this system in the North; however, component design and operation must

TABLE 2. Aerostat and Installed Equipments.

	Hazard
Fabric-hull, fins, ballonet	T
Guy lines	T IW
Pressurization subsystem	
Blowers (AC & DC)	TSI
Air valves - electric	TSI
Helium valves - electric	TSI
Helium valve - mechanical	TSI
Control circuitry	T
Transducers	T
Meteorological subsystem	SI
Power subsystem	
Battery backup	T
Power up tether	---
Hull electrical	---

Note: T = Temp; S = Snow; I = Ice; W = Wind.

TABLE 3. Mooring Subsystem.

	Hazard
Tower	
Nose Cone	SI
Swivel/Tilt Mount	I
Telescoping Pole	SI
Guy Wires	I
Anchors	----
Mooring mount (bed)	
Nose Rope & Closehaul Winches	TSI
Walking Surfaces	SI
Swivel Bearing	I
Tall Support Bags	TSIW
Winch Operators Station	TSIW
Helium Line	I
Power Lines	I

Note: General consideration will be made in selection of material & design of components to take into account minimum temperatures and maximum winds. Flag of T, S, I or W indicates special design areas.

Note: T = Temp; S = Snow; I = Ice; W = Wind.

TABLE 4. Tether Subsystem.

	Hazard
Kevlar	T
Inner jacket	T
Outer jacket	TSI
Braid	T
Swivel	I
Upper end treatments	SIW
Lower corona rings	SIW
Insulator	TSIW
Upper corona rings	SIW
Lower end treatment	SIW
Corona rings	SIW
Connection point	SI
Clamp	SI
Tether washer	T
Solvent	T
Scrubbers	T
Dryers	T
Deicer	
Rollers	TSIW
Ice deflector	TSIW
Flying shieve heater	T I
Flying shieve scraper	T I
Feed point	SI
Power conductors	----
Helium refill tube	T

Note: T = Temp; S = Snow; I = Ice; W = Wind.

TABLE 5. Electrical Subsystem.

	Hazard
Inductor	T
Oil heating/cooling	TSI
Oil pump	TSI
Top corona ring	SIW
Pole	SIW
Feed	SIW

Note: T = Temp; S = Snow; I = Ice; W = Wind.

take the environment into account. Specifically, the following should be done:

1. The fabric composition should be selected and tested for the anticipated temperature range to ensure it will maintain its flexibility, rip, shear, and burst strength.
2. The fabric should be specified and tested to meet minimum helium permeation requirements after folded storage, cold soak, inflation, and ascent to altitude.
3. Blower, anemometer and valve inlets should be deiced to allow operation in the weather extremes anticipated.
4. Equipment packages should be insulated and heated to maintain the specified operating temperatures.
5. All subsystem equipment should be specified and tested to ensure startup after a long, cold soak at specified representative temperatures.
6. The system design should be optimized to minimize inflation time, particularly with respect to the manual lacing and attachment of lines, fittings, hardware, etc., to the hull after inflation, to minimize personnel operations which require them to be exposed outside for extended periods of time.

MOORING SUBSYSTEM

The mooring subsystem presents the greatest challenge. Due to the cold, ice, and snow, the potential exists for burying or immobilizing the mooring system, either with the aerostat moored or flying.

Although its design is very conducive to ice formation, the mooring system must be exposed to the elements. Its sheaves and lines are greatly hampered by ice buildup. Accumulation of snow and ice loads also affect the rotational mass and impose additional loads on the moored aerostat. Finally, if the mooring system is obstructed with ice during a calm wind period, it may be prevented from rotating into the wind as the wind builds up, potentially hazarding the aerostat.

Proposals for designing a northern mooring system to meet these challenges exist, but they contain serious reservations about the prospects for a large aerostat system in this environment [11,15]. The principal reason for these reservations, in this author's opinion, is that not all available assets have been utilized. In the section on methods which follows, I will address the use of these additional assets.

TETHER SUBSYSTEM

The tether subsystem consists of the tether itself, the electrical feed from the electrical subsystem, and any required corona rings and insulators. The insulator used for ELF operations in prior tests may not be required in a new ELF or ELF/VLF system design. The original ELF tests only included the insulator to satisfy a contract requirement which should not exist in future designs. Since a VLF-only system does not require the insulator or corona rings of an ELF/VLF system, they would not be a factor for such a system.

The primary impact from northern operations will be in the selection of tether materials to ensure sufficient flexibility, ductility, and strength at the temperatures present. In addition, a method for deicing the tether on inhaul will be required [15].

Tether mechanical strumming occurs in current aerostat systems. Atmospheric icing of the tether will aggravate this problem. Prior research into atmospheric icing of transmission lines [17] may shed some light on how to mitigate the effects of this problem.

Finally, a mechanical ice cracker will have to be installed ahead of the tether flying sheave to facilitate removal of ice over that portion of the tether which was flying in the icing altitude band.

ELECTRICAL SUBSYSTEM

The electrical subsystem (ES) presents the least design challenge for operation in the North. The control area which will need proper insulation can be treated like any other personnel shelter. Provision should be made to ensure that the equipment will survive in the event of power failure and resulting loss of heat [18].

Proper drip paths will have to be provided at the output bushings. Since the inductor produces significant heat while operating, additional heat may not be required during ELF system operation. A shelter for the inductor area will be required during hours of system shutdown.

Establishing a good system ground will be the major problem faced by the ES. The design and layout of a ground plane system will pose a significant challenge. The U.S. Army Corps of Engineers Cold Regions Research Laboratory (CRRL) has done research into this problem. Henry points out that "the electrical resistivity of frozen soil can be several orders of magnitude higher than unfrozen soil," and "the contact resistance between grounding electrodes and the soil, which is usually negligible under unfrozen conditions, can become significant" [19]. Methods which have been tried in the past are reviewed, and analytical methods discussed in Henry [19].

PERSONNEL

The day-to-day operations of running an aerostat site in the northern regions should not be significantly different from the daily operations now conducted in these regions by commercial oil companies or the scientific community. The primary hazard to personnel in the northern regions comes from freezing of exposed flesh. Personnel are subject to this hazard anytime they are outdoors in these weather areas; however, most routine functions which require outdoor exposure can be delayed past the weather extremes which present the greatest hazard. Where this hazard requires special attention is during aerostat launch and recovery operations, when launch personnel *must* be exposed to the full extent of the weather for up to 1/2 h at a time and the option to delay their exposure may not be available.

Considerable experience exists from commercial, military, and scientific operations in both the Arctic and Antarctic in how to clothe personnel for the weather extremes of these regions. Manuals and instructions developed over years of use are available from the appropriate military commands in each of the services [22].

VI. POTENTIAL SOLUTIONS

With only one exception, the potential solutions addressed here are not revolutionary or radically different from that proposed in prior studies. The major difference is that with the problems better understood in advance, they can be addressed in the design phase where equipment and operational procedures can be tailored to minimize the environmental impacts.

The problems in order of severity are:

1. Snow and ice on site and equipment;
2. Wind and temperature extremes during frontal passage;
3. Personnel windchill hazard.

Table 6 summarizes some of the problems and their solutions.

SNOW AND ICE

Snow accumulation on the ground is potentially the greatest single problem for an aerostat system in certain locations in the North. At coastal locations, ground snow accumulation and drift will require either that the snow be removed or prevented from accumulating or that the system be built high enough to be clear of the average annual snow depth at the site selected [11]. This latter choice is acceptable only for a permanent site and, even then, will result in a system which is very large.

For a transportable system to be feasible in a coastal environment subject to heavy snow accumulation, it would have to be ship- or barge-based. By basing the system on a ship or barge operating free of ice, any substantial snow accumulation can be pushed over the side before it reaches a level that would hinder operations. Figure 25 depicts a ship-based ASET system. Figures 26 and 27 depict a barge-based system for northern operation.

A land transportable system is feasible if operated away from areas with heavy precipitation. Installation of drift fences at a temporary land site away from heavy snowfalls should be sufficient to

TABLE 6. Potential Solutions.

- Wind
  - Design to flight winds
    State-of-the-art

- Snow
  - Optimize design to reduce impact and pocket areas
  - Use snow scraper and blower within state-of-the-art

- Fog
  - Not a factor, solved in snow and ice solutions

- Ice
  - Develop movable feed point (allows altitude variation)
  - Operate above icing altitude
  - Adequately heat flying shieve
  - Flying shieve scraper
  - Tether ice rollers
  - Deicing spray (moored)
  - Utilize waste heat
  - Electrical mooring system deicing
    heaters
    significant design factor for Mooring Subsystem
    (@ -2° C /K', 25 K' alt, and icing band of -12° to 2° C, aerostat will operate above icing)

- Temperature
  - Select materials suitable for temperature, i.e., special alloys of steel or aluminum
  - Optimize hull fabric
  - Optimize tether jackets
  - Provide make up helium
  - Heater blankets for specific components
  - Utilize generator waste heat
  - Utilize generator power when offline

  Significant work here, but feasible

prevent drift accumulation over short periods of time. For longer operations, snow clearing equipment may have to be included in operational planning. This might be as simple as a snowplow on the front of one of the system tractors.

Prevention of snow and ice accumulation is the key to successful operation in Arctic areas. If the system type is optimized for the area of operation (i.e., ship- or barge-based for transportable coas-

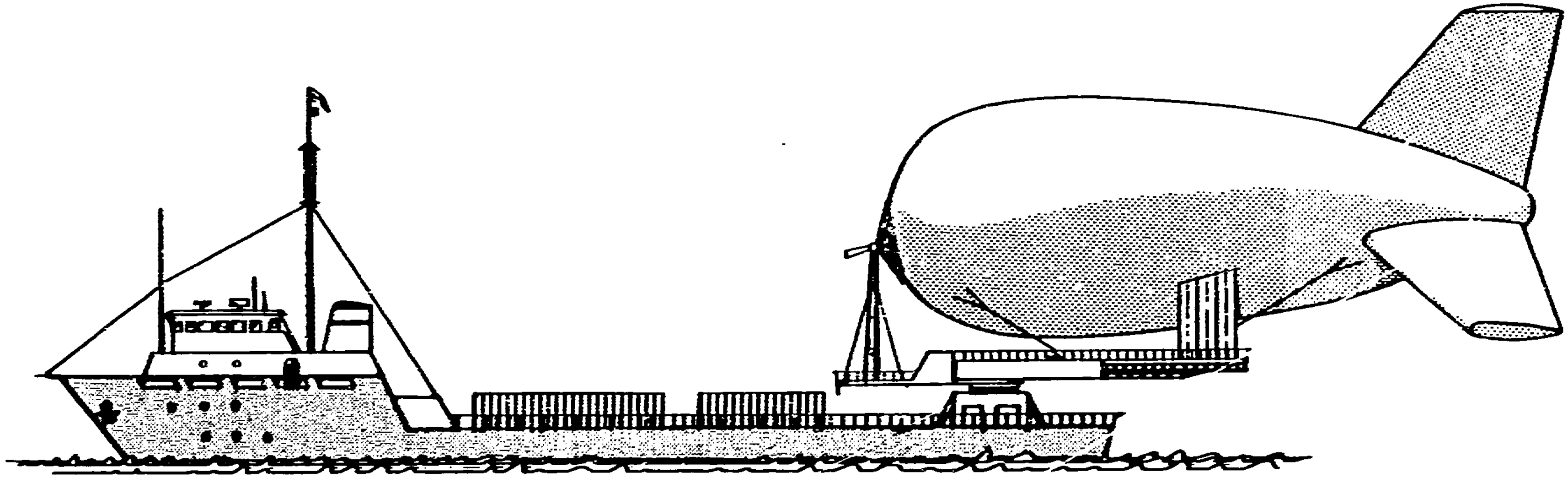


Figure 25. <u>ASET basing options - ship-based.</u>

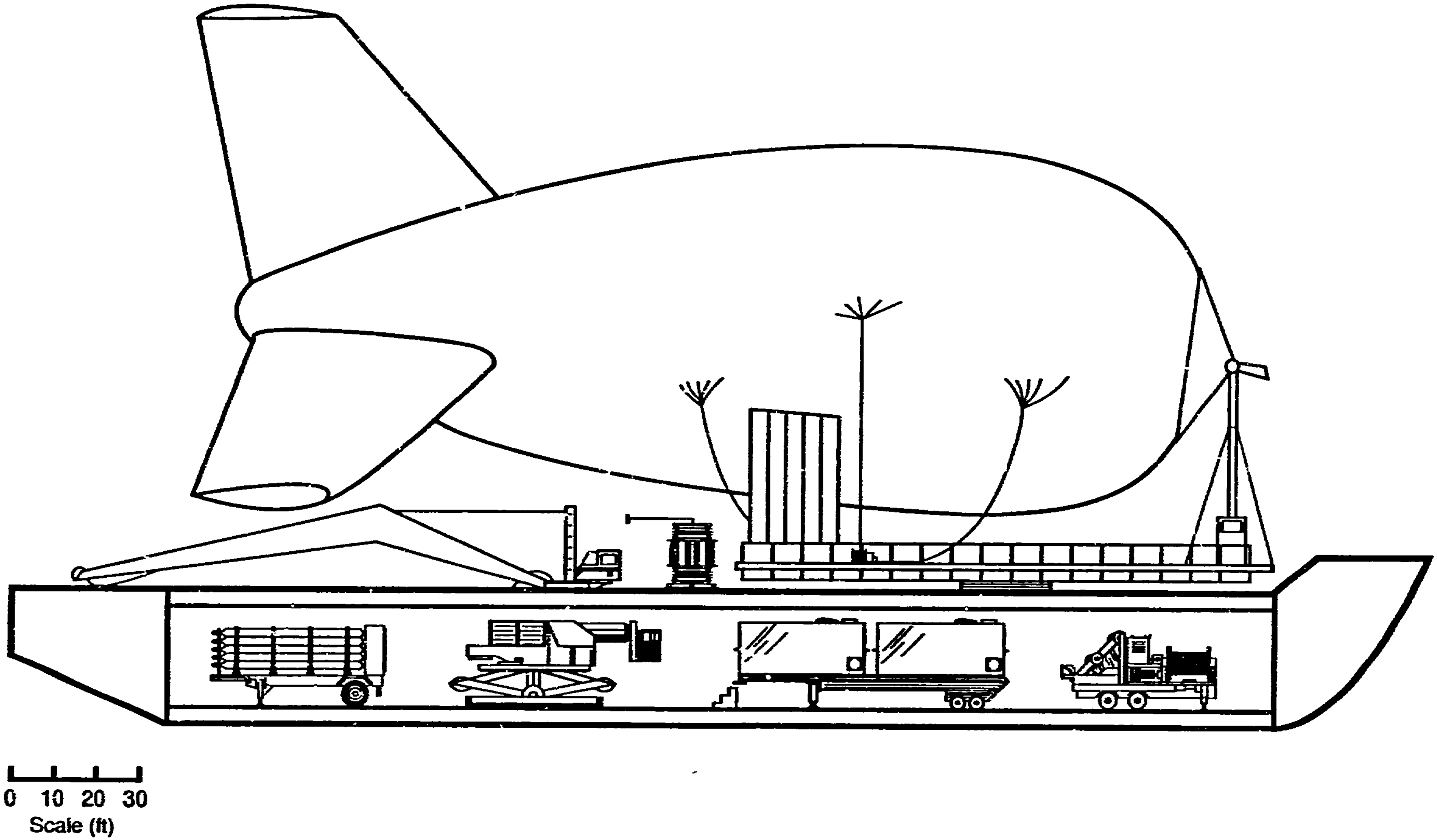


Figure 26. Barge-based ASET - side view.

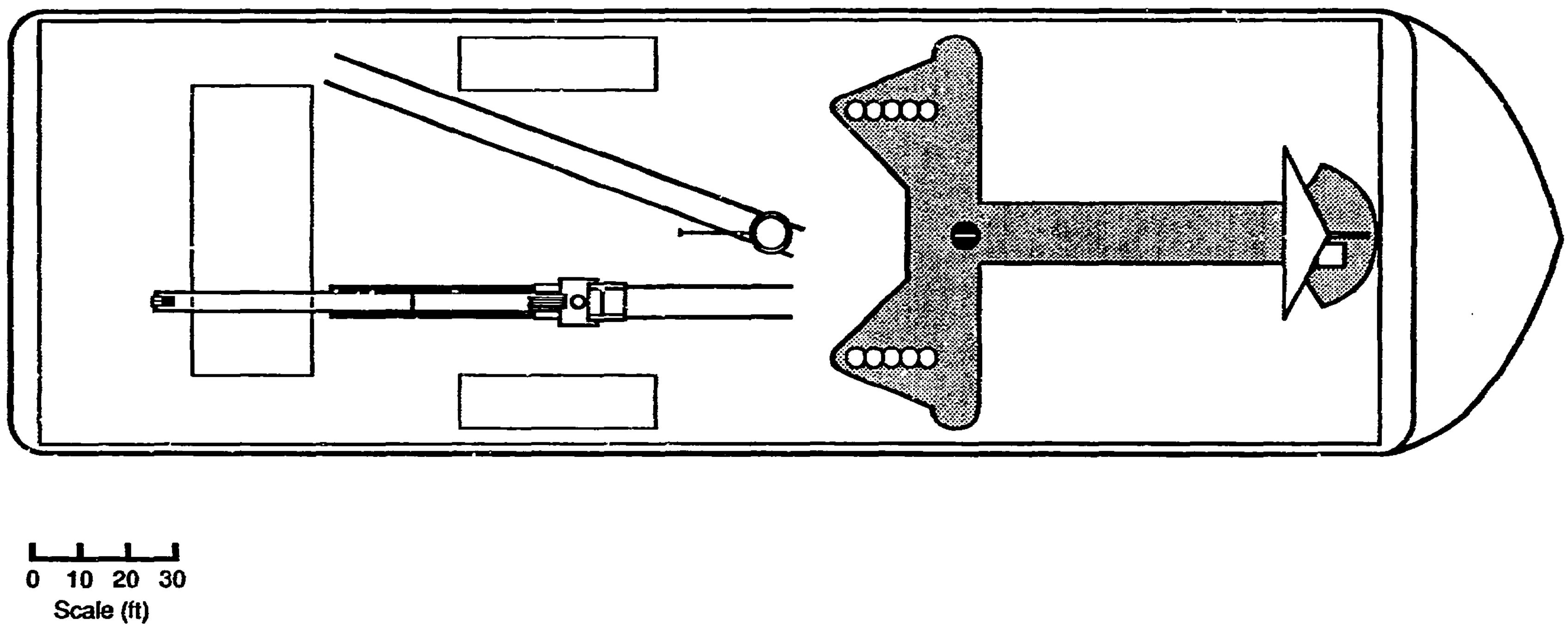


Figure 27. Barge-based ASET - top view.

tal operations, etc.), it will be assumed that the snow and ice accumulation on the mooring system, personnel shelters, and transport vehicles, is limited to that which would normally accumulate from precipitation over the site area only, or icing due to spray.

The areas to be deiced include:

1. Mooring tower and nosecone;
2. Closehaul winches and flying sheave;
3. Tether feed;
4. Aerostat when moored;
5. Inflatable equipment deicing shelter;
6. Critical walkways.

Methods for deicing the aerostat when moored have been successful in the past [15]. Snow accumulation when flying is not a problem; however, icing is [15]. Hydrophobic coatings to prevent ice buildup on the aerostat fabric while flying have been tried [15,20] with minimal success, but this area deserves further development [23].

Many methods of snow and ice removal for a moored aerostat were discussed in the reference material [4,15]; however, none of these methods is suitable for a long-term operation. Spraying the aerostat with a glycol solution is acceptable for occasional use, but the real answer is to keep the aerostat flying and out of the snow and ice.

Prevention of icing in incidentally heated areas on existing mooring systems operated in cold climates has been reported [15], but the significance of this solution was missed.

For a high-power ASET system there would be substantially greater waste heat and electrical generation capability than is normally associated with an aerostat operation. Assuming the ASET system had an antenna input power of about 500 kW utilizing an efficient digital power amplifier, prime power requirements would be about 750 kW. This size system would reject about 585 kW of waste heat to its cooling system at approximately 190°F, an additional 990 kW of waste heat through its exhaust gas at approximately 1000°F, and about 138 kW of waste heat to the atmosphere from its engine. This amounts to ap-

proximately 1.7 MW of total reject heat at any time the generator is run at rated load. In addition, if the transmitter were not operating and the electrical output were directed to strip heaters, an additional 750 kW would be added to the system heating capacity for a total of about 2.5 MW.

Heat tracing [21] methods have been used for many years by the commercial tug industry which operates barges to the North Slope of Alaska. They use it to keep their foredecks clear of ice for line handling. With the waste heat and electrical heat generation capability discussed above, there is more than enough energy to keep the mooring system, moored aerostat, walkways, work areas, and tether electrical feed clear of ice and snow. Another reserve could be created by manifolding the heat sources so that they could be concentrated in a specific area, such as the mooring system, during heavy influx periods.

Ice accumulation on the aerostat while flying remains the one problem which has not yielded to any fieldwork to date, and is one for which no good theoretical solution has been proposed. One solution which comes to mind from the references [4,11,15], and the nature of ASET type operations, is to simply fly clear of the freezing levels. The meteorological data indicates that the freezing level is at the surface for many months and the winter sky is relatively cloud free [7]. The summer months are very cloudy; however, these layers are thin cirrus, typically 1100-1700 ft thick [7]. It should be possible to fly at an altitude which will keep the aerostat clear of icing except during frontal passage and during ascent and descent.

Deicing for the tether during inhaul was discussed earlier, and would potentially consist of running the tether through an "S" bend over open curved rollers to crack the ice before it meets an ice scraper ahead of the flying sheave.

WIND AND TEMPERATURE EXTREMES

High winds are not new to aerostats, but the very high peak winds and extreme cold temperatures in the North will require that the system be designed for more strength. While it is within state-of-

the-art to design the system to generally survive these extremes, an early decision as to whether the system is to be airborne (and at what altitude) or moored will be required since no personnel can be outside during these periods.

The consistently cold temperatures will mean a generally higher free lift, and since the aerostat will operate without cloud cover during most of the winter months, additional superheat will also help lift. With the exception of frontal passage, winds at altitude should generally be light to moderate and not cause a problem.

During both ends of the extreme velocity excursions, better pitch trim control would be desirable. If ice or anything else causes an increase in pitch during a high wind condition, the resulting increase in frontal area drag will cause a very rapid rise in tether tension, with the potential for aerostat loss from broken tethor. Conversely, in low winds with cloud cover, low pitch could result in insufficient free lift.

Installation of a commandable pitch control system could alleviate this problem. This could be accomplished by designing the aerostat with two ballonets and using blowers and valves to control the inflation of each separately. This would move the center of lift, and thus the static trim point, while at altitude. Such an approach would only work at altitudes below the helium vent altitude and would cause the aerostat to weigh more, thereby potentially requiring a larger aerostat for the same payload.

Selection of the correct materials for the anticipated temperature range has already been addressed and would apply generally to all materials used in this environment. Alloys with a brittle point below the temperatures to be encountered should be available; therefore, I do not anticipate a design problem in this area.

PERSONNEL WINDCHILL HAZARD

Assuming personnel manning a northern ASET system are properly clothed, the freezing risk can be minimized, but still must be taken into account. The freezing risks which must be accounted for are water immersion, conductive cooling, and windchill. For the purposes

of this report, it is assumed that any personnel subjected to water immersion, where water has penetrated the insulative clothing to any degree (from a wet toe to full body immersion), will be *immediately* removed to a heated, sheltered area for a change of clothing and treatment of frostbite resulting from the exposure. Similarly, since *properly clothed* personnel are, *by definition*, protected from conductive cooling, this hazard will be ignored for the purposes of this report leaving windchill our primary area of concern.

With the exception of hands and face, insulation of the body to protect from windchill for the period of a launch or recovery is not overly difficult. Heat loss will be proportional to the temperature differential between the body and the environment (the gradient) and the convective loss factor.

Protection of the hands is made more difficult since it usually involves a loss of dexterity. The typical tasks which must be accomplished during a launch or recovery include line handling and bending onto a winch, and hookup of confluence point hardware. Special emphasis will have to be made in the design to allow for the reduced dexterity associated with gloves or mittens for those tasks which must be accomplished without shelter. Winch design, installation, and operation must allow sufficient clearance for ropes with ice *and* gloved hands which may require twice as much working room as normal. This design must still allow for rapid and simple operation, as the current design does, to minimize the exposure time and the aerostat recovery time.

To facilitate ground maintenance, routine system checks might be conducted from an inflated enclosure, thereby protecting personnel from the environmental hazards. Heat supplied by heat tracing might also be used to warm the work area, or heat could be supplied from electric heaters in essential areas.

VII. CONCLUSIONS

Design of an aerostat to operate in the northern latitudes is achievable. This is not a new or isolated conclusion. The original airships of the Hindenberg and Graf Zeppelin era had to address operations in these same latitudes. They operated successfully, albeit in a limited fashion [24].

The major element which will determine success or failure is the advance planning and preparation conducted in selecting a site, understanding the meteorology of the selected area, and ensuring that it is a match for the intended aerostat operation.

Properly approached, aerostat operations in the northern latitudes are feasible.

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